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THIS REPORT IS A RESULT OF AN INVESTIGATION PROGRAM TO DEFINE THE CONDITIONS UNDERLYING THE UPPER ALLUVIUM IN THE VICINITY OF BASIN F. IT DESCRIBES THE METHOD OF INVESTIGATION, DRILLING AND SAMPLING PROCEDURES (BOTH SOIL AND WATER SAMPLES), LIMITED LABORATORY TESTING (PHYSICAL AS WELL AS CHEMICAL), WELL TESTS, (I.E. SLUG TESTS) TO DETERMINE FIELD COEFFICIENT OF PERMEABILITY AND TRANSMISSIVITY OF SAND STRATA, GEOPHYSICAL LOGGING AND INTERPRETATION OF RESULTS.

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BASIN F CONTAINMENT HYDROGEOLOGY ASSESSMENT
ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO

A REPORT ON RESULTS OF DEEP DRILLING ACTIVITIES

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August 1979

DRAFT

Prepared for

Rocky Mountain Arsenal
Denver, Colorado
and
U. S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

PREFACE

This investigation was conducted during the period 5 February to 15 July 1979 by personnel of the Geotechnical Laboratory (GL) of the U. S. Army Engineer Waterways Experiment Station (WES) under the Contamination Control Program of the Rocky Mountain Arsenal (RMA), Commerce City, CO. Funding for this study was authorized by IAO No. RM 62-79, dated 15 February 1979.

This report was prepared by several members of the Engineering Geology and Rock Mechanics Division (EGRMD) of the GL with the advice, consultation, and recommendations of personnel in the Soil Mechanics Division, GL, and the Environmental Engineering Division, Environmental Laboratory. The report was prepared under the direct supervision of Dr. D. C. Banks, Chief, EGRMD, and the general supervision of Mr. J. P. Sale, Chief, GL.

Special acknowledgement is extended to the following individuals for their assistance and review of findings: Messrs. Ed Berry, Irvin Glassman, Don Cook, Brian Anderson, Greg Ward, and Carl Loven of RMA; and Messrs. Andrew Anderson, James Zarzycki, and Don Campbell, U. S. Army Toxic and Hazardous Materials Agency, Edgewood Arsenal, MD.

Commanders and Directors of WES during the preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND
METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	U. S. Customary to Metric (SI)	
inches	2.54	centimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
acres	4046.856	square metres
feet per day	0.3048	metres per day
gallons per year	0.003785412	cubic metres per year
Fahrenheit degrees	0.555	Celsius degrees or Kelvins*
	Metric (SI) to U. S. Customary	
millimetres	0.03937007	inches
centimetres per second	0.3937007	inches per second

* To obtain Celcius (C) readings from Fahrenheit (F) readings, use the following formula: $C = 0.555(F - 32)$. To obtain Kelvin (K) readings, use: $K = 0.55(F + 459.67)$.

BASIN F CONTAINMENT HYDROGEOLOGY ASSESSMENT

ROCK MOUNTAIN ARSENAL, DENVER, COLORADO

A Report on Results of Deep Drilling Activities

PART I: INTRODUCTION

Background

1. The Rocky Mountain Arsenal (RMA) is located northeast of the city of Denver, Colorado, and adjoins the north extent of the Denver Stapleton International Airport (Figure 1; from Kolmer and Anderson, 1977). Since its establishment in 1942, activities involving chemical, biological, and incendiary munitions production as well as chemical munition demilitarization have been carried out within the confines of the RMA. Wastes from these activities were at various times discharged into naturally occurring topographic low areas (i.e., Basins A, B, C, D, and E) and into a specially prepared area (i.e., Basin F). The detection of contaminants in 1974, in surface and subsurface waters, led to three Cease and Desist Orders (7 April 1975) being issued by the Colorado State Department of Health to operations of the RMA (as well as its tenant, the Shell Chemical Company) to:

- a. Immediately stop off-post discharge (both surface and subsurface) of diisopropylmethylphosphonate (DIMP) and dicyclopentadiene (DCPD).
- b. Take action to preclude future off-post discharge (both surface and subsurface) of DIMP and DCPD.
- c. Provide written notice of compliance with Item a.
- d. Submit a proposed plan to meet the requirements of Item b.
- e. Develop and institute a surveillance plan to verify compliance with Items a and b (paraphrased from Miller, 1978).

Because of the Cease and Desist Orders, as well as concern by U. S. Army personnel, a program of contamination recognition, identification,

treatment, and control was placed under the direction of the U. S. Army Toxic and Hazardous Material Agency (USATHAMA) (previously, the Project Manager for Chemical Demilitarization and Installation Restoration (PM CDIR)), Aberdeen Proving Ground, Maryland.

2. The strategy employed by the USATHAMA in complying with the Cease and Desist Orders involved investigation and definition of the quantity and quality of surface and subsurface waters (i.e., that contained in the Pleistocene alluvium) as influenced by surface topographic and subsurface hydrogeologic factors. Incremental studies began at the north boundary of the RMA, where the bulk of contaminants were evidently leaving the confines of the RMA, and progressed southward to locate contaminant sources and determine intervening flow paths from source areas to the northern boundary. Investigation and definition work included both geotechnical and water treatment studies. The geotechnical investigations during the incremental studies, for the most part, were limited to the upper alluvium.

3. Separate studies (e.g. Timofieff, 1976; Buhts and Francinque, 1977) indicated that although Basin F was conceptually designed as a watertight (i.e., lined) basin, it was most likely a contributory source of contamination and was leaking contaminants at least into the upper alluvium. As a result of these indications, a study was performed to quantitatively evaluate the condition of Basin F and its contribution of contaminants into the upper alluvium, determine the geotechnical characteristics of soils within the upper alluvium, and present rationales for eliminating Basin F as a contaminant source (Miller, 1978). That study recommended a full depth (i.e., into unweathered shales of the Denver formation) bentonite slurry cutoff wall completely encircling Basin F.

4. During the incremental studies, primary interest centered upon determining the geotechnical characteristics of materials as well as groundwater conditions in the upper alluvium. Consequently, borings (with their associated well screens for determining water level data and obtaining water samples for quality testing) were considered sufficiently deep if they penetrated the upper alluvium and encountered the underlying Denver shales (or as it has been commonly termed - "bedrock").

However, during the incremental studies a few borings penetrated into the Denver formation to encounter "bedrock" sand strata that were interpreted at times to be possibly interconnected with the upper alluvium. Recognition of the possible interconnectivity, naturally, gave rise to questions concerning the configuration of materials within the Denver formation beneath Basin F and the likely response of groundwater within these materials were Basin F to be completely enclosed with a slurry cutoff wall as recommended by Miller. Several deep borings exist in the vicinity of the RMA but unfortunately they were not drilled, sampled, or logged for the purpose of providing either engineering or geological data for the depths of interest. As a consequence of these concerns and the lack of data, several conversations were held by telephone or face-to-face among representatives of the USATHAMA, RMA, and the U. S. Army Engineer Waterways Experiment Station (WES), concerning possible courses of action to determine the characteristics of sand strata within the Denver formation. Those conversations culminated in an agreement reached in a meeting in USATHAMA offices on 19 January 1979 to pursue an investigation program to define the conditions underlying the upper alluvium in the vicinity of Basin F. The investigation program was described in an Implementation Plan transmitted by letter dated 15 February 1979, subject: Basin F Containment Hydrogeology Assessment, from Mr. Fred Brown, Technical Director, WES, to Commander, RMA.

5. Authority to reimburse WES for the work described in the Implementation Plan was furnished by Intra Army Order No. RM 62-79 dated 15 February 1979. Work actually started on 5 February 1979.

Scope of Report

6. This report describes the method of investigation, drilling, and sampling procedures (both soil and water samples), limited laboratory testing (physical, as well as chemical), well tests (i.e., slug tests) to determine field coefficient of permeability and transmissivity of sand strata, geophysical logging, and interpretation of results. The Implementation Plan and funding authority described two other activities:

a. Field support of a civil engineering technician from WES to develop the observations wells, to take water level measurements and aid in well tests, and to obtain water quality samples, and

b. Install a newly available, multilevel, water quality sampling casing.

The former activity is supportive of work reported herein as well as other projects and need not be reported separately. The latter activity will be the subject of a subsequent report.

Geologic Setting

7. The RMA is underlain by layers or lenses of clays, silts, sands, and gravels varying in aggregate thickness of up to approximately 60 ft. These soils are generally referred to as the "alluvial aquifer," "upper aquifer," or "upper alluvial materials," or "alluvium." At the base of the alluvium lies an unweathered clay shale or shale layer (termed, in the past, as the "bedrock surface"). This underlying surface is the subcrop of the Paleocene (lower Tertiary) Denver formation. The Denver formation contains clays (or clay shales), sands, siltstone and sandstone layers or lenses, and a variable thickness (described as being up to 100 ft)* basal shale (but also described as containing sandy materials).* The shale strata is part of the Denver formation and is considered by personnel of the State of Colorado Division of Water Resources to be a "buffer zone" forming the basal Denver formation which overlies the Cretaceous Arapaho formation. The project borings were extended to partially penetrate the "buffer zone" materials so that a description could be made of materials occurring within the Denver formation (i.e., upper bedrock). Such information would:

a. Allow, for the first time on the RMA, an engineering geologic description of the materials.

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* Personal communication with John C. Romero, State of Colorado Department of Natural Resources, Division of Water Resources.

b. Provide information on the occurrence, quantity, and quality of groundwater within the Denver formation, and

c. Provide a monitoring system for determining the long-term behavior of the groundwater in the underlying materials, especially in response to future remedial efforts on the RMA.

8. In particular with respect to Item b above, combinations of occurrence, quantity, and quality information could be configured into four possible situations, as paraphrased from the Implementation Plan.

Condition Determined in Denver Sand Layer(s)	Conclusion
1. a) Piezometric head different from that in the alluvium b) No contamination	Denver sand layer(s) not connected with the alluvium (in the vicinity of Basin F)
2. a) Piezometric head same as that in the alluvium b) No contamination	Denver sand layer(s) are connected with the alluvium (in the vicinity of Basin F). Contaminants have not reached the Denver sand layer(s)
3. a) Piezometric head same as that in the alluvium b) Contamination present	Denver sand layer(s) are connected with the alluvium (in the vicinity of Basin F). Contaminants are reaching the Denver sand layer(s) with present boundary conditions
4. a) Piezometric head different from that in the alluvium b) Contamination present	Denver sand layer(s) are not connected with the alluvium (in the vicinity of Basin F). Contaminants are reaching the Denver sand layer(s) with present boundary conditions but from sources other than in the vicinity of Basin F

PART II: STUDY PROCEDURES

General

9. Four pilot borings referred to as Deep Borings (DB) -1, -2, -3, and -4 were drilled at the approximate southwest, northwest, northeast, and southeast "corners," respectively, of Basin F as shown in Figure 2. (These pilot borings carry RMA series nos. of 493, 494, 495, and 496, respectively.) After drilling, soil sampling, and geologic and geophysical logging activities were completed, each pilot boring was grouted from bottom to the ground surface. A small portion of the clays were analyzed in an X-ray diffractometer to determine the clay mineral content. The data obtained were assessed to determine depths and thicknesses of permeable sand layers or lenses of interest in the Denver formation. Satellite borings were made to the predetermined depths of the sand layer and slotted PVC pipe screens were placed to periodically obtain associated water levels and water samples in these layers. The satellite borings are referred to as DB-1-1, DB-1-2, DB-2-1,..., DB-4-3. (In subsequent text, the satellite borings are referred to both as piezometers or wells, since they serve a dual purpose.) In all, nine such satellite borings were made. The positions of satellite borings relative to their associated pilot boring is shown on the inserts in Figure 2.

10. After the PVC screen was placed, procedures, described subsequently, were followed to develop the well for water sampling and water level measurements; and to perform slug tests to determine in situ coefficients of permeability and transmissivity for each stratum of interest. Periodically, using procedures described subsequently, water samples were withdrawn from each well for water quality determination. Before the PVC pipe screen was placed, an undisturbed soil sample was obtained where the screen was to be placed. These samples were returned to WES, X-rayed to determine soil structural features, and tested to determine grain size distribution (i.e., classification), dry density, water content, and coefficient of permeability in the laboratory. Each

cluster of deep borings lies close to one or more "shallow" borings, made as part of the Miller, 1978, study in which well screens were placed within but generally near the bottom of the alluvium. Information from the deep pilot borings, their associated satellite borings and nearby "shallow" borings formed the basis for conclusions reached in this report.

Drilling, Sampling, and Sealing of Pilot Borings

11. The deep drilling program was accomplished during the period 5 February through 25 April 1979 using two WES truck-mounted, Failing model 1500, rotary drill rigs. The pilot (sample) borings were drilled using bentonite drilling fluid for hole stability and improved sample recovery. The pilot borings were drilled and continuously sampled for the full depth using a 3-in. in diameter, 30-in.-long Pitcher sampler except for the following intervals:

DB-1	25.6 - 32.0 ft
	34.5 - 41.1 ft
	49.0 - 52.2 ft
DB-2	20.0 - 30.0 ft
	161.1 - 167.5 ft
	212.7 - 216.1 ft
	224.2 - 226.2 ft
DB-3	20.0 - 50.6 ft

Gravelly zones and sandstone layers were encountered within the depth intervals listed above. Since these layers could not be penetrated with the Pitcher sampler, a rock bit was substituted with the result that no samples were retrieved. After each pilot boring penetrated the alluvium, the hole was reamed to 7-3/4 in. in diameter and 6-in.-ID flush joint steel casing was set and seated in the underlying clay-shale layer (i.e. Denver formation) to prevent communication of groundwater between the alluvial and bedrock aquifers during pletion of the boring. The

average required length of casing was about 50 ft. After drilling, sampling, and geologic and geophysical logging were completed, each boring was grouted from bottom to top with a Portland cement and bentonite mixture to displace the drilling fluid. Approximately 25 percent of bentonite (by volume of dry materials) was added to the Portland cement to compensate for shrinkage of the grout and insure a positive seal between the aquifers. Upon completion of the grouting, the steel casing was removed.

Geophysical Logging of Pilot Borings

12. Before each of the four pilot holes were grouted, downhole geophysical logs were obtained by a logging contractor. Two runs were required to obtain all logs. During the first run, spontaneous potential (also called self-potential), resistivity, and natural gamma logs were obtained. During the second run, neutron and duplicate natural gamma logs were obtained. The duplicate natural gamma log was made for ease of comparison and interpretation of data. The neutron log was not obtained in boring DB-1.

13. These geophysical logs supplement the lithologic log when interpreting the characteristics of the Denver formation. Whether analyzed individually or compared with other downhole logs, these logs provide data to allow interpretation of variations in permeability, porosity, density, shaliness, and occurrence of water.

Drilling and Sampling of Satellite Borings

14. The 7-3/4-in. in diameter satellite (piezometer or observation well) borings were drilled through the upper alluvium using bentonite fluid. Each satellite boring was extended approximately 5 ft into the uppermost clay-shale strata in the Denver formation into which a 6-in.-ID PVC pipe was set and grouted from bottom to top as a permanent seal to isolate groundwater in the Recent-Pleistocene alluvium from groundwater in the Denver formation. The grout used was the same as

described in para 11. The remainder of the boring was drilled 5-5/8 in. in diameter to the predetermined depth using only water as the drilling fluid. Schedule 40, 2-in. PVC pipe was placed in the boring with a slotted screen section situated through the permeable zone of interest. A 5-ft-long sediment trap (2-in. solid-wall PVC pipe) was set below the screened section to compensate for sand infiltration and to provide space, if necessary, to conduct slug tests. Clean concrete pea gravel (minus 3/8-in. mesh) was placed around the screen portion as a filter and allowed to settle. The annular space between the 2-in. PVC pipe and the side of the boring above the filter was first sealed by placing a 5-ft-thick layer of bentonite balls, then the remainder of the boring was grouted from bottom to top with the Portland cement and bentonite grout as described in para 11.

Well Development

15. The observation wells were developed in accordance with methods previously used by RMA personnel for small diameter (2-in.) wells. This method consisted of placing an air hose down to the bottom of the sediment trap and injecting compressed air to force the column of water up and out of the casing. The placement of the hose within the sediment trap, which extended 5 ft below the screened interval, initiated the movement of water upward and minimized injection of fluid through the screen and into the permeable zone of interest. Air flow was continued until the entire column of water in the casing was removed. The water in the well was then allowed to recover to between 33 and 100 percent of its original height before again being blown out. This process was repeated six times to insure adequate groundwater flow into the well. Some of the wells which were screened in strata of low permeability were slow to recover.

Water Level Measurements

16. Water level measurements were taken using a conventional "M-scope," a battery-powered electrical probe which uses the slight

electrical conductivity of water to sense the water surface. The "M-scope" probe was lowered slowly down the casing of each of the satellite borings, while monitoring the needle of an electrical conductivity meter wired in parallel across the probe. As long as the probe remained in air the electrical conductivity remained negligible (resistivity of air being virtually infinite). Immediately upon contact of the probe with the water surface within the casing, the needle displaying electrical conductivity on the meter showed a marked deflection (increase in conductivity, decrease in resistivity to finite values). By maneuvering the probe up-and-down across the air-water interface, the actual contact point of the probe with the interface was identified with a relatively high degree of accuracy. The distance between the top of casing and the air-water interface was read from calibration marks on the wire connecting the probe to the meter. The elevation of the water surface (piezometric surface) was determined by subtracting this measured distance from the surveyed elevation of the top of casing. Although these measurements are usually accurate, with proper exercise of caution, within ±0.05 ft, the measurements were usually reported to the nearest 0.1 ft.

17. Initial water level measurements were made prior to well development. Since several of these measurements differed substantially from readings taken subsequent to well development these readings were not used in interpretation. After well development, water levels were routinely measured prior to initiation of standard sampling procedures described below.

Water Quality Sampling

18. Each well placed during the deep drilling program was developed and used to obtain samples for water quality analysis. The methods used for sampling have been standardized for WES participation on RMA projects. The procedure is described as follows:

- a. Measure depth from top of casing to top of water. Record depth for future use in development of groundwater contour map.

b. Measure depth from top of casing to the bottom of well casing (total depth of cased hole) for initial sampling of new installation or use previously recorded depth for resampling of established installation.

c. Subtract depth to top of water from depth to bottom of casing to determine the height of standing water in the casing.

d. For every foot of standing water:

(1) Remove 1.5 gal of water, if well is pumped, or

(2) Remove 3 bailer volumes (5-ft bailer), if well is bailed.

e. If well goes dry before pumping or bailing is complete, allow the well to recover and again empty the well.

f. Immediately recover a sample for chemical analysis after pumping or bailing is complete (Step d). In case a well is pumped or bailed dry, recover a groundwater sample as soon as possible while the well is recovering the second time.

g. Notes:

(1) The sampling bailer or pump should be flushed with clean water after sampling to prevent cross contamination between sampling wells.

(2) All samples for chemical analyses should be placed in glass jars. A piece of aluminum foil should be placed over the top of the jar prior to securing the jar lid. (This foil protects the sample from any plastic on the inside of the cap.) The sample should be placed in a box immediately after recovery (to prevent exposure to sunlight), and delivered to the laboratory as soon as possible.

19. Water quality samples were recovered in accordance with the standard procedure on 10 April and 17 April, and submitted to RMA, Material Analysis Laboratory Division (MALD), for routine chemical analyses. A review of data showed the wells were t at eq librium; consequently, two additional sets of samples were obtained on 5 June and

18 June. The samples recovered for inclusion in this report were analyzed for the same chemical parameters as in the contamination survey. These parameters were: aldrin, chloride, O-sulfone, O-sulfoxide, DBCP (nemagon), DCPD, DIMP, dithiane, dieldrin, endrin, fluoride, isodrin, oxathiane, and O-sulfide.

Slug Tests

20. Slug tests were conducted in each satellite boring to determine the coefficient of permeability and transmissivity of strata at depths of the slotted sections of PVC pipe. In a slug test the water level in a well is lowered essentially instantaneously by rapidly removing a fixed volume of water with a bailer followed by observation of the change in water level with time. For each satellite boring the change in water level, as determined from the response of a pressure transducer, was recorded on an oscillograph recorder.

21. Data from the slug tests were evaluated using analytical procedures that allowed the field boundary conditions to be approximated to the maximum possible extent. The field conditions which were encountered were as follows:

- a. Semiconfined and confined flow conditions in the Denver sands,
- b. Multiple aquifers of finite thickness and infinite extent (with respect to the radius of the wells),
- c. Fully penetrating well screens, and
- d. Transient or nonsteady state flow conditions (during tests).

Three analytical procedures were considered for evaluation of the test data; Hvorslev (1951), Bouwer and Rice (1976), and Cooper et al., (1967). Hvorslev addressed conditions a (partially) and c (partially) of the above list, while Bouwer and Rice addressed conditions a (partially), b, and c. Cooper et al., addressed each of the four boundary conditions, either directly or indirectly, by using a nonsteady flow differential equation to provide an exact solution for the heads in and around a well

after a known volume of water is instantaneously withdrawn from the well. The Cooper et al., method was used to evaluate all tests except the test in well DB-2-2, which exhibited a steady state flow recovery curve and consequently required analysis by the Bouwer and Rice method. Inherent with the use of the Cooper et al., method for the remaining test data was the assumption that well storage, aquifer storage, and nonsteady state flow must be considered to accurately evaluate an aquifer's response to a slug test (Cooper et al., 1967; Black, 1978; Walton, 1978; and Boulton and Streltsova, 1976).

Physical Testing

22. Undisturbed samples taken from the satellite borings at the depths of the PVC screened intervals were returned to WES, X-rayed to determine soil structural features, and delivered to personnel of the Soils Testing Facility, Geotechnical Laboratory, to determine the natural water content, dry density, grain size distribution (for classification purposes), and laboratory determination of the coefficient of permeability. Test methods employed were in general accordance with the Corps of Engineers Manual for Laboratory Soils Testing (EM 1110-2-1906, 30 November 1970).

PART III: DATA PRESENTATION

23. Field data used in preparing descriptive logs of borings DB-1, -2, -3, and -4 are contained in Appendix A. The graphical presentation of the data is shown in Figures 3 through 10. Each paired figure (i.e., Figures 3 and 4 for boring DB-1; Figures 5 and 6 for boring DB-2, etc.) graphically shows the stratigraphy, description of materials, water level data, and geophysical logs. Classification symbols are in accordance with the Unified Soil Classification System (USCS). Table 1 presents the geographic coordinates and ground elevations of the deep borings and existing borings near them. Elevations of the top of casing and depth to the top and bottom of screens are also presented for the identified piezometers.

24. The stratigraphy at the depths of each well screen is shown in Figures 3, 5, 7, and 9. Figure 11 shows the change in water level as a function of time for each slug test. The data and evaluation of each slug test are shown in Table 2.

25. Laboratory data sheets from which the water contents, dry densities, coefficients of permeability, and grain size distributions were determined for materials in which the well screens were placed are contained in Appendix B. Figures 12 through 20 indicate the grain size (gradation) curves, USCS designation as well as the coefficient of permeability for each sample. A summary of laboratory data is shown in Table 3.

26. Water quality data from the deep borings are shown in Tables 4 through 7.

PART IV: STUDY RESULTS

Geologic Interpretations

27. A review of literature describing studies of the Cretaceous and Tertiary sediments in the Denver Basin was made to obtain the latest information concerning the "bedrock" geology in the vicinity of Basin F. Those studies that described the depositional environments of these sediments and their stratigraphic positioning in relation to some widespread easily mappable datum (i.e., formation) were reviewed in detail. Materials deposited under marine conditions are usually more continuous and homogeneous than those deposited in most nonmarine environments and consequently make better datum planes. Materials deposited in nonmarine environments usually contain individual lenses of clays and sands which are discontinuous and often pinch out within short areal distances. Despite the inherent sporadic nature of nonmarine fluvial sediments, local mappable trends do occur.

28. In the area of the RMA, several hundred feet of cyclic, superpositioned nonmarine and transitional sediments (Denver, Arapaho, Laramie, Fox Hill formations, etc.) overlie the relatively continuous, homogeneous marine Pierre shale. The stratigraphic positions of bedrock units underlying the Basin F area have been located and correlated across the Denver Basin from available deep borings (to Pierre shale) and an electric log (E-log) section (Romero, 1976). This E-log section, which included information obtained from the deep injection (Derby) well on the RMA, indicated that sediments underlying the Recent-Pleistocene alluvium should correlate stratigraphically with materials identified as the lower part of the Denver formation (Paleocene). A trend of fine-grained, clay shale, approximately 75 to 100 ft thick in the basal part of the Denver formation, was designated as the "buffer zone" and can be seen on the E-log section to extend across the Denver Basin. This very fine-grained trend exists at approximately the same stratigraphic position in relation to the Pierre shale datum. It is also important to note that a similar thickness of clayey shale often occurs above and/or

below the "buffer zone." Although the "buffer zone" is present in most areas across the Denver Basin, it should not be viewed in the same sense as a more widespread and more homogeneous datum such as the Pierre shale. The "buffer zone" is used primarily to separate the Denver and Arapaho formations in deep water wells and has never been identified previously at the outcrop or in cores; from this use, the "buffer zone" should not be considered as a lithologic entity.*

29. Data from the deep injection (Derby) well was used to develop a local section in the Basin F area; extensive consultations were made with personnel from the State of Colorado, Division of Water Resources, in developing the section. This section indicated that a fine-grained clayey interval from a depth of 170 ft (elevation 5017 MSL) to 260 ft (elevation 4927 MSL) correlated closely with the "buffer zone." Lithologically this interval is similar to clayey layers located stratigraphically higher or lower and was chosen solely on the basis of E-log correlations with the E-log section across the Denver Basin.

30. Since a reasonable stratigraphic correlation could be established with the regional geology in the study area, the deep drilling program was originally planned to penetrate through the alluvium, the Denver formation (including the "buffer zone"), and into the Arapaho formation by some 20 to 30 ft. However, this plan was later altered to terminate the borings in the "buffer zone" because the Arapaho formation is the major aquifer in the Denver area and personnel of the State of Colorado, Division of Water Resources, recommended (by letter)** that any drilling in areas underlying known industrial contamination should terminate in the "buffer zone."

31. A discussion of findings in each of the four pilot borings and how the findings correlate is presented in the following paragraphs. Boring DB-4 will be discussed first because the surface elevation is the

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* Personal communication with John C. Romero, State of Colorado Department of Natural Resources, Division of Water Resources.

** Letter from Colorado Department of Natural Resources, Division of Water Rsources, to Mr. Don Cook, RMA, April 1977.

highest of the four pilot borings and was used as a stratigraphic reference for the remaining three pilot borings.

Boring DB-4

32. Boring DB-4 was drilled to a depth of 231 ft. The top 48 ft penetrated alluvial clays, sands, and gravels. The interval from 48.0 to 55.5 ft contained oxidized silty clay probably deposited in a deltaic swamp or shallow lake. The interval from 55.5 to 77.3 ft contained a reddish-brown oxidized medium- to coarse-grained sand which represented a fluvial deltaic distributary channel (Figure 21). The sand coarsened downward from fine grained at the top to very coarse grained at the base. The oxidized condition of the sand was a result of nearby downcutting which exposed the Denver sands to the surface during the Pleistocene. Nearby sand at this same stratigraphic position was unoxidized. For discussion purposes this sand is designated as fluvial channel trend A. The term "trend" is more appropriate for this type of sand body than "layer" or "bed" because deltaic channel sands are lenticular in nature and tend to pinch out laterally away from the channel axis whereas "layer" or "bed" might imply widespread areal correlation. Piezometer DB-4-1 was placed in trend A. Materials in the 77.3- to 95.8-ft interval consisted of very compact silts and clays emplaced as natural levee and delta swamp sediments. These materials have a relatively low hydraulic conductivity and transmissivity as compared to the channel sands. Deltaic deposition is often cyclic and this pattern was verified by the channel sand trend within the 100.8- to 126.9-ft interval which was almost identical in nature to sand trend A. Stacked deltaic sand units are the result of the cyclic deposition. This lower interval, which is designated as channel sand trend B, was unoxidized. Piezometer DB-4-2 was placed in trend B. Another thin sandy trend was located from 138.0 to 142.7 ft. This bluish gray, fine-grained, clayey sand probably represented deposition by a smaller localized deltaic deposit and is identified as trend C. Peizometer DB-4-3 was placed in trend C.

33. The material beneath trend C to the bottom of boring DB-4 was predominately compact deltaic clay, clay shale, and silt. Thin low-permeability sandstone lenses, found within the 190.4- to 200.0-ft

interval, contained mostly sand-size clay grains instead of quartz. These intervals represent short periods of high energy erosion and transport with deposition in a normally low-energy environment. Many of the laminated clayey intervals were highly carbonaceous and contained flattened plant fragments and leaf imprints. Some clay lenses were more blocky and montmorillonitic than others. These blocky intervals could have originated during periods of nearby volcanic activity which resulted in large amounts of fine ash being incorporated into the deltaic swamp environment. Montmorillonitic clays are often the result of alteration of volcanic glass shards. Fine-grained montmorillonitic clayey trends of this nature comprised the "buffer zone" in the area of Basin F, but due to active reworking in the delta environment at the time of deposition these clayey intervals cannot be interpreted as a continuous time-lithologic datum. The brown nodules of siderite, or in some cases one of the iron oxides, in the lower part of the test hole may be the result of oxidation in a well-drained deltaic swamp (Figure 22). The lighter colored clays and silts represent deposition in a well-drained swamp, while darker clays represent deposition in poorly-drained swamps or lakes.

Boring DB-1

34. Boring DB-1, which was drilled to a total depth of 225 ft, penetrated 32 ft of alluvial clays, sands, and gravels. The interval from 32.0 to 49.0 ft contained gray clay, overlying material which apparently correlates with the lower part of the Denver trend A located in boring DB-4. The interval from 49.0 to 75.8 ft was composed mostly of deltaic clay and clay shale with thin lignite seams at 63.0 to 63.1 ft and 63.9 to 64.1 ft. The materials throughout this interval were very low in permeability. A greenish gray, medium- to coarse-grained, fairly homogeneous sand occupied the 75.8- to 95.2-ft interval. This sand trend correlates well with trend B as identified in boring DB-4 although it is not as thick. Piezometer DB-1-1 was placed in this trend. The aquifer test results (slug test), discussed subsequently also substantiates the correlation between the two borings. The sediments in the remainder of boring DB-1 (below 95.2 ft) were mostly tight compact deltaic silts,

clays, and clay shales. Thick homogeneous channel sands of the type found in trends A and B, were not encountered below 95.2 ft. Several thin siltstones and clayey conglomeratic lenses were successfully screened between 135 to 157 ft to produce enough water for chemical tests (piezometer DB-1-2). While the geophysical data and samples indicated that this interval was low in permeability it showed the most potential for producing water in the lower half of the test hole.

Boring DB-2

35. Boring DB-2 was drilled to a depth of 245 ft. The upper 45 ft consisted of alluvial silts, sands, and gravels. This 45 ft depth is about the same elevation as the base of sand trend A located in boring DB-4. If lateral continuity is assumed for sand trend A, some of the material at the 30 to 45 ft depth could be weathered or reworked Denver material. Channel sand trends similar to those located in boring DB-4 were absent below the depth of 45 ft. The material from 45.0 to 245.2 ft consisted primarily of carbonaceous, montmorillonitic delta swamp, and lake deposits of low permeability. A partially indurated sandy layer was screened from 155.0 to 180 ft (piezometer DB-2-1). Within this interval, sediments between the depths of 161 and 164 ft were tightly cemented with calcium carbonate; elsewhere thin, nonindurated lenses were encountered. This interval could not be correlated laterally with adjacent borings and is believed to represent local deposition as opposed to a more widespread channel trend. The lower part of boring DB-2 (152 to 245 ft) contained more thin indurated claystone and siltstone streaks (some calcium carbonate cementation) than noted in any of the other deep borings. A second screen (piezometer DB-2-2) was placed from 200 to 220 ft. Sample and geophysical data indicated this interval to be somewhat more permeable than the material lying directly above or below, but is still extremely low in permeability as compared to the channel sand trends A and B in boring DB-4.

Boring DB-3

36. Boring DB-3 was drilled to a depth of 242 ft. The upper 50.6 ft consisted of alluvial silty to clayey sands and gravels. Hard layers within the lower part of this interval may be Denver siltstone or

sandstone but no samples were recovered with the sampling method used (Pitcher sampler). The proximity of these hard layers near the contact between the Denver formation and overlying recent alluvial sediments often hampered identification of the exact contact.

37. The sediments in boring DB-3 from 50.6 to 150.0 ft were composed of alternating thin lenses of clay, silt, and fine sand. The environments of deposition for these materials were probably similar to those described by Weimer (1976). He describes sands grading laterally from channel trends into natural levee silts and clays, to well-drained swamp clays, to poorly-drained swamp clays (lignite or coals) and, finally, into lake or bay sediments (Figure 22). This interpretation explains why the channel sand trends found in boring DB-4 do not occur in borings DB-3 or DB-2. The environment of deposition had shifted away from channel development to levee and swamp conditions. The sediments in the 150.0- to 242.6-ft interval suggested a shift from well-drained swamp and natural levees to poorly-drained swamps or lakes. This condition yielded a higher percentage of clay and a reduction in percentage of sand and silt.

38. An interval containing several thin, partially indurated conglomeratic (clay ball) sandstone layers was screened from 87 to 107 ft (piezometer DB-3-1). A 75-deg joint was noted in this interval with gray clay being in sharp contact with brown sand. The oxidized condition of the sand along this contact indicated groundwater flow.

39. The screen in piezometer DB-3-2 was placed from 130 to 150 ft. The geophysical data and core samples showed this interval to be composed of thinly bedded compact siltstones and sands of relatively low permeability. The majority of the water from this interval comes from a gray fine- to medium-grained compact sand between 146.0 and 149.0 ft.

Geologic relationships

40. The review of the literature (principally Romero, 1976) indicates that a "buffer zone" approximately 75 to 100 ft thick, comprised of fine-grained clay shale, should exist in the basal part of the Denver formation beneath Basin F. The base of the Denver formation, from regional information, dips approximately S20°E at about 100 ft

per mile. The local information obtained from boring logs, sample inspection, and geophysical logs confirms that such a "zone" exists beneath Basin F as shown in Figure 23. While the borings did not penetrate the "buffer zone" so that its thickness or regional dip could be confirmed, Figure 23 is constructed with strata dipping in conformance with the regional dip. The stratigraphic interval corresponding to the "buffer zone" at the base of the Denver formation was determined to contain swamp and lake deposits with a high content of montmorillonitic clay and thus should be considered relatively impermeable in the area of Basin F. The "buffer zone" is not a homogeneous time-stratigraphic unit like the marine Pierre shale. Since the "buffer zone" was deposited in a deltaic environment, it contains sand lenses in certain areas. The "buffer zone" is used primarily to separate the Denver and Arapaho formations in deep water wells and should not be considered as a lithologic entity.

41. The review of the literature (principally Weimer, 1976) further indicated that the materials in the Denver formation lying above the "buffer zone" are nonmarine, lenticular deposits of sands, clays, and silts. While trends do occur, the nature of the deposits were highly responsive to changes in depositional environment. Identification of such trends was made from boring logs, sample inspection, and geophysical logs, and are depicted in Figure 23. The depictation shows the alluvium and Denver sands to be interconnected. Local environments of deposition for the Denver were interpreted as being deltaic distributary channels (sand), natural levee (silt and clay), well-drained swamp (light gray to brown clay), poorly-drained swamp (dark carbonaceous clay and lignite), and lake or bay (dark clay, silt, and sand). The channel sands are the most permeable media, and therefore the most important from a hydrogeologic standpoint.

42. Relatively permeable channel sands were correlated south, east, and northeast of Basin F. The strike-and-dip of these trends could not be adequately determined from the four pilot borings. While conclusive data are not available, Figure 23 was constructed with a regional dip in the Denver formation of S20°E at about 100 ft per mile as in the underlying Arapaho (Romero, 1976). If the Denver formation

dips to the southeast, the areas to the southwest and northeast of Basin F would be along formational strike and the units would still remain relatively flat. In any case, the Denver sands in the Basin F area trend north and east toward the north boundary of the RMA in the vicinity of First Creek. From stratigraphic projections (using boring DB-4 as a reference and assuming a certain degree of continuity) Denver formation sand trends A and B appear to intersect the overlying alluvium in the vicinity of Basin F; trend A in the southern part and B near the northeast corner.

43. The possibility of structural features such as faults, grabens, or anticlines cannot be ignored in the Basin F area. Numerous slickensided joints and abrupt clay-sand contacts were noted in core samples. An ongoing study of an igneous or sedimentary dike on Rattlesnake Hill (south of Basin F) by the Colorado School of Mines and the U. S. Geological Survey should contribute important data. The alignment of Rattlesnake Hill, Harrington Hill at the GB Plant, and Henderson Hill with a nearby producing oil field could reflect deep structural control. These three hills are gravel capped bedrock highs. Other anomalies along this linear trend are a thick coal seam that is truncated or disappears laterally and a sharp 90-deg deflection of First Creek. None of the above anomalies are conclusive evidence of structure, but should be considered along with hydrogeologic anomalies in the area to identify the presence of structural feature(s).

Interconnectivity of Aquifers

44. A primary purpose of the deep drilling program around Basin F was to determine if the alluvial aquifer and Denver formation sands were interconnected. Geologic evidence indicates that the materials are interconnected. A possible connection between the alluvium and sand trend A in the Denver formation was found in boring DB-1. A more definite connection was found in RMA test hole No. 972 located just east of boring DB-3 (Figure 23). With the stratigraphic sequence found in

boring DB-4, and some degree of continuity being assumed for sand trends A and B, it is possible that as the topography becomes lower to the north and northeast of Basin F, and intersects the planes of these projected trends, numerous areas of interconnection could occur. Many borings in these areas seem to support this concept.

45. Additional evidence supporting the interconnection of alluvium and Denver sands is given by the relationship between piezometric heads in the deep and shallow piezometers.

Piezometric levels-
vicinity of boring DB-1

46. Figure 24 shows piezometric levels at various dates during the study period in shallow borings Nos. 436, 440, and 444 and for deep piezometers DB-1-1 and DB-1-2. The figure shows the height of water above midscreen plotted against the midscreen elevation. On such a plot hydrostatic relationships are represented by locus of points inclined at 45 deg. As shown, the piezometric levels in shallow borings Nos. 436, 440, and 444 show a consistent hydrostatic relationship. (Figure 2 and Table 1 show boring No. 489 to be in the vicinity of boring DB-1; however, the piezometric level at boring 489 is below the screen.) The piezometric levels in deep borings DB-1-1 and DB-1-2 show a similarly consistent hydrostatic relationship. However, the deep piezometers show a level approximately 14 ft lower than that indicated from the shallow piezometers. Tabulations in Figure 24 as well as plots in Figure 3 show the trends indicated to be relatively constant during the study period.

47. These piezometric observations are interpreted to indicate that the lower Denver sands are interconnected to the upper alluvial aquifer at locations down gradient, i.e., to the north of boring DB-1. It should also be noted that the piezometer in shallow boring No. 444 is located in an upper Denver sand (most likely in sand trend A). The consistency of piezometric levels in boring No. 444 with levels in boring Nos. 436 and 440 which are in the alluvium indicate that sand trend A is interconnected with the alluvium in the vicinity of boring DB-1.

Piezometric levels-
vicinity of boring DB-2

48. Figure 25 shows piezometric levels in shallow borings Nos. 418, 421, and 422 and for deep piezometers DB-2-1 and DB-2-2 (see Figure 2 and Table 1). (Boring 487 is in the vicinity of DB-2 but the piezometric level was below the well screen.) The piezometric data for the shallow borings are not sufficient to establish a hydrostatic trend but do indicate a piezometric level of from 7 to 12 ft higher than the hydrostatic trend indicated by piezometer DB-2-1. Piezometer DB-2-2 is the only piezometer associated with this study that was placed within the "buffer zone." The piezometer came to equilibrium extremely slowly but by the 29 May 1979 reading apparently had equilibrated (see Figure 5) at a piezometric level approximately 18 ft lower than that indicated by piezometer DB-2-1.

49. These piezometric observations are interpreted to indicate that the lower Denver sand layers are interconnected to the alluvium at locations to the north of boring DB-2.

Piezometric levels-
vicinity of boring DB-3

50. Figure 26 shows piezometric levels in shallow borings No. 478 and 480 and deep piezometers DB-3-1 and DB-3-2 (see Figure 2 and Table 1). Figure 7 shows the piezometric levels in the deep piezometers to be constant throughout the study period. Figure 26 shows the piezometric levels in both the shallow and deep piezometers to be hydrostatic and consistent among each other.

51. These piezometric observations strongly suggest that the Denver sand layers are interconnected with the upper alluvium in the immediate vicinity of boring DB-3. Due to the depth of these lower sands and the lack of contamination however, additional data will be needed for more detailed study.

Piezometric levels-
vicinity of boring DB-4

52. Figure 27 shows piezometric levels in shallow borings No. 464 and 491 and deep piezometers DB-4-1, DB-4-2, and DB-4-3 (see Figure 2

and Table 1). In other shallow piezometers in the vicinity of boring DB-4 (Nos. 456, 458, and 460) the piezometric levels were lower than the well screen. The data indicate that a reasonable hydrostatic trend is established in the shallow piezometers. Figure 9 indicates that the deep piezometric levels have been fairly constant throughout the study period. Data displayed in Figure 27 show that the piezometric level in DB-4-1 is consistent with the hydrostatic trend established in the shallow piezometers. The two lower piezometers DB-4-2 and DB-4-3 establish a second hydrostatic trend that is about 20 ft lower than that in the alluvium.

53. These piezometric observations indicate that the Denver sands (trend A) is interconnected to the alluvial aquifer in the vicinity of boring DB-4. The lower sands (trends B and C) apparently are interconnected at locations to the north of boring DB-4.

General comparisons
of piezometric levels

54. Figure 28 shows piezometric levels from all deep piezometers on a common plot. In all, four hydrostatic trends are indicated. The uppermost trend (through DB-4-1), as has been discussed, is indicative of groundwater level in the alluvial aquifer in the immediate vicinity of boring DB-4. The second trend is consistent with piezometers DB-1-1, DB-1-2, DB-4-2, and DB-4-3. Since borings DB-1 and DB-4 are located approximately along formational strike, such a relationship should be anticipated. The third trend is consistent with piezometers DB-2-1, DB-3-1, and DB-3-2. Again, since borings DB-2 and DB-3 are located approximately along formational strike, the relationship was anticipated. The lower trend is supported by the piezometric level in piezometer DB-2-2.

55. Figure 29 conceptually depicts the subsurface conditions of Basin F. The figure shows a section through Basin F approximately perpendicular to lines connecting borings DB-1 and DB-4 and borings DB-2 and DB-3; the section is thus approximately along the regional dip in the underlying formations. A groundwater surface is shown with a gradient to the northwest. A regional dip of 100 ft per mile is shown

connecting the deep piezometers with the contact between the alluvium and the underlying Denver formation. This concept would indicate that the piezometric head at DB-4-2 (point a) would equal the difference in elevation between point a and point b. By this concept the piezometric levels in the lower sands should be less than the piezometric level associated with the alluvial aquifer in the immediate vicinity of individual borings. Again, Figure 29 is produced to indicate a concept. The groundwater surface in the alluvial aquifer, the contact between the alluvium and the Denver formation as well as the regional dip show variations in the Basin F area. Also, local modification in stratigraphy, as discussed previously, may modify the concept. For example, piezometric levels in sands in which piezometer DB-3-1, DB-3-2, and DB-4-1 were placed are interconnected with the alluvium in the immediate vicinity of borings DB-3 and DB-4, respectively.

Water Quality

56. The chemical analyses of the water samples obtained from the deep piezometers are presented in Tables 4 through 7. As shown in the tables, concentrations of many of the contaminants were found to be below detectable limits. For those contaminants found to be above detectable limits, the results from each sample collected from a particular piezometer were reviewed to determine if equilibrium conditions had been reached as indicated by more or less consistent concentrations of contaminants being found in successive samples. The concentrations were found to vary in many cases (except in the case of the last two samples from DB-4). Because of the variations, it was not possible to conclude that the wells had reached equilibrium. Therefore, the data can be viewed only as an indication of the presence or absence of contaminants. The wells must be permitted to reach equilibrium before a quantitative assessment of the data can be made.

57. A qualitative assessment of the data was made based on the significance of the reported concentrations with respect to detection limits and with respect to the presence or absence of the contaminants

in successive samples. Some data were considered inconclusive in cases where the concentration of a contaminant was only slightly higher than the detectable limit, particularly where the contaminant was identified in only one of the successive samples. Such anomalies could have resulted from uncontrollable cross contamination during sampling or analysis, especially since many of the concentrations found were near the detection limit for the analytical procedures. Continued sampling and analysis should provide some clarification of these anomalies.

58. Water samples collected from piezometer DB-1-1 (southwest of Basin F, Figure 2) were found to contain chloride, sodium, and fluoride; DIMP was also found above detectable limits in two samples. In DB-1-2, water samples again were found to contain chloride, sodium, and fluoride; only one sample contained DIMP at a concentration above the detectable limit. The chloride and sodium concentrations found were not significant. Fluoride concentrations in the 4 ppm range in two samples from DB-1-2 are above background levels and could indicate some pollutant migration, although no significant concentrations of other contaminants were revealed in samples from that piezometer. DIMP concentrations in DB-1-1 were not consistent and therefore the significance of these results was inconclusive.

59. Water samples collected from piezometer DB-2-1 (northwest of Basin F, Figure 2) were found to contain chloride, sodium, and fluoride; DIMP at a low concentration was found in one sample. Water samples from DB-2-2 likewise contained chloride, sodium, and fluoride; DIMP was found in two samples, and Nemagon was found in one sample. Chloride and sodium concentrations were not significantly high. Two samples from DB-2-2 had fluoride concentrations above 4 ppm, which along with the DIMP and Nemagon concentrations may indicate pollutant migration, although the data were inconclusive because of inconsistencies.

60. Chloride, sodium, and fluoride were found in samples of water collected from piezometer DB-3-1 (northeast of Basin F, Figure 2). DIMP was found in one sample and O-sulfoxide was found in another, both at low concentrations. Samples from DB-3-2 were found to contain chloride, sodium, and fluoride; DIMP was found in one sample. Chloride concentrations were not significantly high. Sodium concentrations in DB-3-1 were

higher than in samples taken from other piezometers in the study, with the exception of DB-4-1. Concentrations of other contaminants found were inconsistent and therefore the significance of this data was inconclusive.

61. Water samples collected from piezometer DB-4-1 (southeast of Basin F, Figure 2) were found to contain chloride, sodium, and fluoride. DIMP and Dieldrin were found in three samples, and Isodrin was found at a low concentration in one sample. Chloride, sodium, and fluoride were found in DB-4-2. DIMP was found in one sample, and Dieldrin was found in two samples. Water samples from the lower piezometer, DB-4-3, were found to contain chloride, sodium, and fluoride. Dieldrin was found in three samples and a low concentration of Isodrin was found in one sample. Chloride, DIMP, and Dieldrin concentrations in DB-4-1 were significantly high and indicate pollutant migration into this sand trend. Fluoride and Isodrin concentrations in the samples from DB-4-1 were not significantly high. Chloride, sodium, and fluoride concentrations in DB-4-2 and DB-4-3 were not significantly high. Dieldrin concentrations in DB-4-3 probably represent a pollutant migration into this trend, although other contaminants not naturally occurring were not found. Dieldrin was also found in samples collected from DB-4-2, indicating possible pollutant migration. Concentrations of other contaminants found were inconsistent and therefore the significance of the data for these contaminants was inconclusive.

62. Results from the samples collected from the various piezometers were compared. It should be noted that the three contaminants chloride, sodium, and fluoride occur naturally in RMA groundwater. Background levels for these contaminants in the Denver sand trends are not known and may vary widely even between trends. Therefore, comparison of concentrations of these contaminants does not necessarily indicate the connection or separation of the trends. The occurrence of other contaminants such as Dieldrin in the three piezometers at DB-4 probably does indicate some connection between the trends. A comparison made of results from DB-1-1 and DB-4-2 (the two piezometers thought to be placed in the same trend) was not conclusive. Dieldrin was found in DB-4-2 but

not in DB-1-1. The range of concentrations of the other contaminants was similar.

63. A comparison of contaminant concentrations found in the water in the deep borings was made with those found in the water in shallow borings adjacent to the deep borings (Tables 8 through 11). Many of the adjacent borings had piezometers located in the alluvium, while the deep boring piezometers were placed in the Denver. In general, in DB-1, DB-2, and DB-3, the alluvial water contained more contaminants at higher concentrations than did the water in the deep Denver sands indicating that little migration of contaminants has occurred from the alluvium to the Denver in these locations. In the DB-4 area, the adjacent piezometers are located in upper Denver sands. Contaminant species and concentrations found in water samples from these piezometers are similar to those found in samples from DB-4-1. The results of the Basin A neck area study also verify this migration. Dieldrin concentrations found in water samples at all three levels in DB-4 were not found in samples taken from wells in the neck area study area. The Dieldrin found in water from DB-4 piezometer is probably a localized phenomenon caused by historical activity in this area.

Results of Slug Tests

64. The coefficient of permeability and transmissivity as determined from analysis of the slug tests are shown in Table 2. Values of coefficient of permeability varied from a low of 1.9×10^{-7} cm/sec for the piezometer in the "buffer zone" (DB-2-2) to a high of 7.1×10^{-4} for the piezometer in sand trend A (DB-4-1); associated transmissivity ranged from 2.8×10^{-5} cm^2/sec to 1.9 cm^2/sec, respectively.

65. Only two piezometers were placed in the same sand trend (B). These two piezometers (DB-1-1 and DB-4-2) indicated consistent coefficient of permeability (2.2×10^{-3} cm/sec and 1.9×10^{-3} cm/sec, respectively), as well as transmissivity of 1.9 cm^2/sec for both piezometers. It should be noted that the laboratory determination of grain size distribution (Figures 12 and 19) and coefficient of permeability were similarly consistent for samples taken at the piezometer locations.

66. No attempt should be made to obtain average values of coefficients of permeability; the values are dependent upon several factors that are strongly influenced by the environments of deposition. It is sufficient to note that lower sands in the Denver formation exhibit values typically ranging from 10^{-7} to 10^{-5} cm/sec; values in the alluvium typically range from 10^{-4} to 10^{-2} cm/sec. From this large difference in the coefficient of permeability (approximately three orders of magnitude) groundwater movement in the lower sand layers will be much slower than movement in the upper aquifer. However, the Denver channel sands in the deep borings with permeabilities of 10^{-4} cm/sec would move water at a similar rate as the alluvial aquifer.

Comparison of Field to Laboratory Coefficients of Permeability

67. Future analysis of groundwater flow on the RMA will require information concerning proper values of the coefficient of permeability. Such information will no doubt come from a variety of sources (i.e., field pump tests, field slug tests, laboratory permeability tests, correlations with grain size parameters, etc.). Some limited information concerning the relationship between laboratory and field determined values of the coefficient of permeability was generated by this study, Figure 30. Whatever inferences that are made by the relationship indicated by Figure 30, should be made considering that the coefficient of permeability determined in the laboratory is influenced by sample disturbance, test technique, specimen preparation, etc., and that the flow is in an axial direction with respect to the borehole. Thus, in a layered system, the coefficient of permeability is reflective of the least permeable layer. The coefficient of permeability as determined from field tests is influenced by borehole disturbances, test techniques method of analysis, etc.; the flow is in a radial direction with respect to the borehole. Thus, in a layered system, the coefficient of permeability is reflective of the most permeable layer.

68. Insufficient data exist to establish a relationship between the coefficients of permeability and grain size.

PART V: IMPLICATIONS OF FINDINGS

69. The Miller (1978) study was based on determining the most reliable means to isolate Basin F as a source of pollution of the alluvial aquifer. The study recommended a bentonite slurry trench with interior dewatering wells as the best alternative for containing horizontal groundwater flow in the alluvial aquifer beneath Basin F. In the recommendation, a slurry trench would be constructed completely around Basin F to a depth (estimated to average about 60 ft with a maximum of about 80 ft, but) sufficient, as indicated by a series of shallow borings, to be tied into strata of low permeability. The general conditions that are characteristic of the geology at RMA was recognized by Miller. In particular the possible connection between the alluvial aquifer and Denver formation sand lenses was cited as a possible problem bearing on the successful employment of a bentonite slurry trench. The results of the present study has verified this interconnection. Miller's study emphasized careful observations of cuttings and sampling of the slurry trench bottom during construction to insure that the trench was founded in low permeability material. Following construction, Miller recommended that the sand strata within the Denver formation be monitored to determine the presence of contamination.

70. While the present study has confirmed the interconnectivity of the sands in the Denver formation with the alluvial aquifer, the findings do not negate the concept of using a bentonite slurry trench to surround Basin F as an effective means of isolating Basin F as a source of pollution. This statement is made in view of the following considerations:

- _a_. The dip of the deeper sands within the Denver formation is so small (estimated to be approximately 100 ft/mile) that the subcrop area most likely is beyond the confines of the recommended slurry trench.
- _b_. Those shallower Denver sands that are directly connected with the alluvial aquifer within the confines of the recommended slurry trench can be isolated by deepening of the trench.

c. The majority of flow beneath Basin F occurs in the alluvial aquifer. Not only is the potential saturated thickness of the alluvial aquifer larger than that of the sands in the Denver formation but the aquifer is more continuous and is characterized by coefficients of permeability that range about three orders of magnitude larger than those in the lower Denver sands.

d. Deep monitoring wells (DB-1-1, DB-1-2,...,DB-4-3) are in place to observe future changes in contamination levels in the Denver sands. If increases are noted in contamination levels the slow groundwater flow velocities most likely existing in the Denver sands will give adequate time to install a lower defense against pollution migration through the installation of dewatering wells at selected locations.

e. If isolated erosional channels are missed or not adequately isolated by the slurry trench or by the deeper dewatering wells, a final defense against off-post migration is offered by the recommended barrier to be constructed at the north boundary of the RMA.

71. Modifications to the presently recommended slurry trench concept include:

a. Deepening the slurry trench to below the depth of sand trend A in the Denver formation in the southern part of Basin F, and possibly below the base of sand trend B in the northern part. From presently available data, the slurry trench should reach the approximate elevation of 5140 ft MSL on the southern part of Basin F and approximately 5100 ft MSL in the northern part.

b. When excavating the trench to its founding elevation, careful observation and inspection of cuttings should be made to insure that the trench is founded in material of low permeability. Should channel sands be encountered beneath this approximate elevation, soundings should be made to determine the thickness of the sand to be followed

by a decision to extend the trench to a depth sufficient to cut off the channel sand, if economically feasible, or, if not, to install a monitoring well outside the confines of the trench.

c. Monitoring programs must be established to observe changes in contaminant levels in Denver sand layers and in any channel sands that are not cut off by the slurry trench.

d. Contigency plans should be made for dewatering wells specifically designed to intersect flows in the channel sands or deep sand lenses should the data so indicate.

72. The data generated by Miller (1978) and this study are sufficiently adequate to proceed with design of the slurry trench barrier except possibly along the east side of Basin B. Along this alignment confusion exists upon the nature by which sand trend A subcrops and the nature of sand trend B. In view of the environment in which these trends were deposited it is thought that additional drilling and sampling would be an extremely expensive and time-consuming activity. Rather it is recommended that a seismic profile be obtained along this alignment to supplement the interpretation of subsurface information. The interpretation of seismic survey results will be aided by the geologic control offered by both deep and shallow borings along the traverse and will better help to define the design depth of the slurry trench barrier.

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Table 1

Basin F Containment Hydrogeology Assessment - Data Associated with Borings of Interest to this Study

Boring No.	Formation	East Coordinate	North Coordinate	Ground Elevation (ft, MSL)	Elevation Top of Casing (ft, MSL)	Depth to Screened Interval Top (ft)	Depth to Screened Interval Bottom (ft)
DB-1 (493)				5197.66			
DB-1-1					5200.62	75.0	95.0
DB-1-2		2,180,058.03	188,105.66		5200.71	135.0	157.0
DB-2 (494)				5185.52			
DB-2-1					5188.20	155.0	180.0
DB-2-2		2,179,058.42	190,171.72		5188.50	200.0	220.0
DB-3 (495)		2,181,127.77	190,462.65	5188.61			
DB-3-1					5191.47	87.0	107.0
DB-3-2		2,181,136.01	190,454.58		5191.88	130.0	155.0
DB-4 (496)				5221.64			
DB-4-1					5224.50	59.0	78.0
DB-4-2					5224.17	97.0	127.0
DB-4-3		2,182,015.24	188,693.20		5224.77	138.0	146.0
436 Near DB-1	Alluvium	2,179,888	188,553	5200.36	5203.61	50.0	54.0
440 Near DB-1	Alluvium	2,180,079	188,203	5200.18	5204.53	43.1	47.1
444 Near DB-1	Denver	2,180,499	188,127	5201.03	5203.18	59.4	63.4
489 Near DB-1	Alluvium	2,179,668	187,767	5190.80	5193.50		
418 Near DB-2	Alluvium	2,179,290	190,197	5193.57	5196.31	46.8	50.8
421 Near DB-2	Alluvium	2,179,300	189,899	5191.89	5193.99	46.6	50.6
422 Near DB-2	Alluvium	2,179,303	189,800	5190.50	5193.26	40.0	44.0
487 Near DB-2	Alluvium	2,178,714	189,763				
478 Near DB-3	Alluvium	2,181,042	190,171	5199.40	5201.47	60.4	64.4
480 Near DB-3	Alluvium	2,180,924	190,028	5195.20	5197.46	56.7	60.7

(Continued)

Table 1 (Concluded)

Boring No.		Formation	East Coordinate	North Coordinate	Ground Elevation (ft, MSL)	Elevation Top of Casing (ft, MSL)	Depth to Screened Interval Top (ft)	Depth to Screened Interval Bottom (ft)
456	Near DB-4	Alluvium	2,181,694	188,146	5205.37	5208.51	33.5	37.5
458	Near DB-4	Denver	2,181,753	188,324	5204.90	5207.17	—	—
460	Near DB-4	Alluvium	2,181,726	188,536	5202.87	5204.66	33.1	37.1
464	Near DB-4	Denver	2,181,679	188,932	5202.78	5204.57	57.5	61.5
491	Near DB-4	Denver	2,182,274	189,002	5217.10	5219.80	54	58

Table 2

Basin F Containment Hydrogeology Assessment Slug Test Results for Sand Lenses in Denver Formation

Boring No.	Screen Depth ft	α*	Permeability cm/sec	Aquifer** Thickness ft	Transmissivity cm^2/sec
DB-1-1	75.0-95.0	10^{-2}	2.2×10^{-3}	27.2	1.9×10^{0}
DB-1-2	135.0-157.0	10^{-5}	1.3×10^{-6}	2.4	9.3×10^{-5}
DB-2-1	155.0-180.0	10^{-5}	5.1×10^{-5}	25.0	3.9×10^{-2}
DB-2-2	200.0-220.0	NA†	1.9×10^{-7}	5.0	2.8×10^{-5}
DB-3-1	87.0-107.0	10^{-5}	2.1×10^{-5}	9.4	6.1×10^{-3}
DB-3-2	130.0-155.0	10^{-1}	8.2×10^{-6}	7.0	1.8×10^{-3}
DB-3-2††	130.0-155.0	10^{-2}	2.1×10^{-5}	7.0	4.4×10^{-3}
DB-4-1	59.0-78.0	10^{-4}	7.1×10^{-3}	21.8	4.7×10^{0}
DB-4-2	97.0-127.0	10^{-3}	1.9×10^{-3}	31.9	1.9×10^{0}
DB-4-3	138.0-146.0	10^{-4}	7.6×10^{-6}	4.7	1.1×10^{-3}

* $\alpha = \frac{(\text{Radius of Screen})^{**}}{(\text{Radius of Casing})^{**}}$ (Storage Coefficient)

** Aquifer thickness = summation of saturated coarse-grained material thickness in the tested interval.

† Boring No. DB-2-2 exhibited a steady-state flow recovery curve, dictating a Bouwer and Rice method of analysis, negating the requirement for α.

†† Permeability calculated for M-scope readings; all other slug tests calculated from transducer measurement.

Table 3

Basin F Containment Hydrogeology Assessment Laboratory Test Results for Sand Lenses in Denver Formation*

Boring No.	Sample Depth ft	Unified Soils Classification System Designation	Pretest Water Content Percent	Pretest Dry Density lb/ft^3	Permeability Test Method	Permeability cm/sec
DB-1-1	80.9-81.5	SP-SM	15.8	107.9	Falling Head	4.8×10^{-4}
DB-1-2	143.0-143.4	CL	41.0	79.8	Falling Head	3.1×10^{-8}
DB-1-2	143.0-143.4	CL	41.0	79.8	Constant Head	3.0×10^{-8}
DB-2-1	156.4-157.0	SM	16.7	111.0	Falling Head	1.1×10^{-6}
DB-2-2	213.9-214.5	CH	19.5	108.0	Falling Head	5.8×10^{-7}
DB-3-1	88.9-89.5	SM	20.8	105.1	Falling Head	1.3×10^{-5}
DB-3-1	89.5-90.0	SM	15.5	110.6	Falling Head	7.9×10^{-5}
DB-3-2	147.9-148.5	ML	20.5	102.7	Falling Head	1.4×10^{-4}
DB-4-1	61.4-62.0	SM	19.7	104.6	Falling Head	4.2×10^{-4}
DB-4-2	101.9-102.5	SP-SM	18.9	106.2	Falling Head	1.3×10^{-4}
DB-4-3	139.6-140.2	CH	15.5	112.1	Falling Head	6.4×10^{-6}

* All tests conducted at a constant confining pressure of 3.0 lb/in^2.

Table 4

Basin F Containment Hydrogeology Assessment Water Quality Data for Borings DB-1-1 and DB-1-2

DB-1-1 RMA Series 493

	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl*	ltdl	ltdl	ltdl
Chloride	ppm	35.0	524.0	33.0	36.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	62.4	2.60	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	1.72	1.51	1.72	1.19
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	129.0	197.0	146.0	188.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

DB-1-2 RMA Series 493

	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl	ltdl	ltdl	ltdl
Chloride	ppm	44.0	56.0	48.0	48.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	ltdl	6.2	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	2.81	1.02	4.06	3.85
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	116.0	370.0	131.0	137.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

Table 5

Basin F Containment Hydrogeology Assessment Water Quality Data for Borings DB-2-1 and DB-2-2

DB-2-1 RMA Series 494					
	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl*	ltdl	ltdl	ltdl
Chloride	ppm	145.0	32.0	149.0	144.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	ltdl	ltdl	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	2.01	1.13	2.37	2.32
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	238.0	186.0	230.0	234.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

DB-2-2 RMA Series 494					
	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl	ltdl	ltdl	ltdl
Chloride	ppm	126.0	509.0	111.0	111.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	0.82
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	52.2	2.60	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	2.94	1.62	4.08	4.2
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	189.0	169.0	161.0	168.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

Table 6

Basin F Containment Hydrogeology Assessment Water Quality Data for Borings DB-3-1 and DB-3-2

DB-3-1 RMA Series 495

	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl	ltdl	ltdl	ltdl
Chloride	ppm	54.0	56.0	57.0	53.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	19.2	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	ltdl	2.30	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	0.96	3.28	1.34	1.27
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	376.0	133.0	349.0	357.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

DB-3-2 RMA Series 495

	Detect Limits	5 Apr 79	17 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl	ltdl	ltdl	ltdl
Chloride	ppm	68.0	74.0	70.0	68.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	ltdl	2.4	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	2.31	2.64	3.09	3.16
Isodrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Sodium	ppm	204.0	194.0	187.0	194.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

Table 7

Basin F Containment Hydrogeology Assessment Water Quality Data for Borings DB-4-1, DB-4-2, DB-4-3

DB-4-1 RMA Series 496					
	Detect Limits	17 Apr 79	30 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl*	ltdl	ltdl	ltdl
Chloride	ppm	56.0	984.0	801.0	826.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	48.8	107.0	113.3
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	4.63	2.77	2.76
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltld
Fluoride	ppm	1.02	0.8	0.85	0.85
Isodrin	0.5 ppb	ltdl	0.8	ltdl	ltdl
Sodium	ppm	370.0	334.0	264.0	279.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

DB-4-2 RMA Series 496					
	Detect Limits	17 Apr 79	30 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl		ltdl	ltdl
Chloride	ppm	144.0		44.0	44.0
O-Sulfone	5 ppb	ltdl		ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl		ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl		ltdl	ltdl
DCPD	10 ppb	ltdl		ltdl	ltdl
DIMP	2 ppb	ltdl		2.80	ltdl
Dithiane	5 ppb	ltdl		ltdl	ltdl
Dieldrin	0.5 ppb	ltdl		1.40	1.74
Endrin	0.5 ppb	ltdl		ltdl	ltdl
Fluoride	ppm	2.13		2.47	2.41
Isodrin	0.5 ppb	ltdl		ltdl	ltdl
Sodium	ppm	232.0		136.0	145.0
Oxathiane	5 ppb	ltdl		ltdl	ltdl
O-Sulfide	5 ppb	ltdl		ltdl	ltdl

(Continued)

* ltdl = les han detectable limits

Table 7 (Concluded)

	DB-4-3 RMA Series 496				
	Detect Limits	17 Apr 79	30 Apr 79	5 Jun 79	18 Jun 79
Aldrin	1 ppb	ltdl*	ltdl	ltdl	ltdl
Chloride	ppm	36.0	51.0	24.0	27.0
O-Sulfone	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfoxide	5 ppb	ltdl	ltdl	ltdl	ltdl
DBCP (Nemagon)	0.4 ppb	ltdl	ltdl	ltdl	ltdl
DCPD	10 ppb	ltdl	ltdl	ltdl	ltdl
DIMP	2 ppb	ltdl	ltdl	ltdl	ltdl
Dithiane	5 ppb	ltdl	ltdl	ltdl	ltdl
Dieldrin	0.5 ppb	ltdl	1.67	2.31	3.9
Endrin	0.5 ppb	ltdl	ltdl	ltdl	ltdl
Fluoride	ppm	1.44	2.13	2.06	2.21
Isodrin	0.5 ppb	ltdl	0.9	ltdl	ltdl
Sodium	ppm	158.0	144.0	138.0	140.0
Oxathiane	5 ppb	ltdl	ltdl	ltdl	ltdl
O-Sulfide	5 ppb	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

(Sheet 2 of 2)

Table 8

Basin F Containment Hydrogeology Assessment, Comparison of Contaminants in Deep Borings with those in Adjacent Borings (Vicinity of DB-1)

Well No.	Formation	Elevation of Screen (ft)	Date	Chloride (ppm)	O-Sulfone (ppb)	DIMP (ppb)	Dithiane (ppb)	Oxathiane (ppb)
489	Alluvium	5156.3-5152.3	14 Dec 78	1110	20.8	110.0	67.8	7.2
			5 Mar 79	1182	15.4	100.0	21.7	25.0
			20 Mar 79	1287	7.8	122.0	10.3	20.5
436	Alluvium	5150.6-5146.6	23 Apr 79	456	18.6	83	14.6	1td1*
			24 Apr 79	522	34.2	104	20.6	1td1
440	Alluvium	5157.1-5153.1	25 Apr 79	435	1td1	330.1	9.4	7.7
444	Denver	5141.6-5137.6	1 Feb 79	167	1td1	34.8	1td1	1td1
			25 Apr 79	184	1td1	22.8	1td1	1td1
DB-1-1		5122.6-5102.6	5 Apr 79	35	1td1	1td1	1td1	1td1
			17 Apr 79	524	1td1	1td1	1td1	1td1
			5 Jun 79	33	1td1	1td1	1td1	1td1
			18 Jun 79	36	1td1	1td1	1td1	1td1
DB-1-2		5062.6-5040.6	5 Apr 79	44	1td1	1td1	1td1	1td1
			17 Apr 79	56	1td1	1td1	1td1	1td1
			5 Jun 79	48	1td1	6.2	1td1	1td1
			18 Jun 79	48	1td1	6.2	1td1	1td1

* 1td1 = less than detectable limits

Table 9
Basin F Containment Hydrogeology Assessment, Comparison of Contaminants in Deep Borings with those in Adjacent Borings (Vicinity of DB-2)

Well No.	Formation	Elevation of Screen (ft)	Date	Chloride (ppm)	O-Sulfone (ppb)	DIMP (ppb)	Dithiane (ppb)	Oxathiane (ppb)
418	Alluvium	5146.7-5142.7	5 Mar 79	674	25.2	412	6.15	5.66
			23 Apr 79	856	20.1	367	1tdl*	1tdl
			24 Apr 79	839	25.1	407	1tdl	1tdl
421	Alluvium	5145.2-5141.2	5 Mar 79	156	1tdl	8.46	1tdl	1tdl
422	Alluvium	5134.3-5130.3	5 Mar 79	595	14.5	1812	28.9	8.3
			23 Apr 79	621	1tdl	2347	21.6	1tdl
DB-2-1		5030.5-5005.5	5 Apr 79	145	1tdl	1tdl	1tdl	1tdl
			17 Apr 79	32	1tdl	1tdl	1tdl	1tdl
			5 Jun 79	149	1tdl	3.4	1tdl	1tdl
			18 Jun 79	144	1tdl	1tdl	1tdl	1tdl
DB-2-2		4985.5-4965.5	5 Apr 79	126.0	1tdl	1tdl	1tdl	1tdl
			17 Apr 79	509	1tdl	52.2	1tdl	1tdl
			5 Jun 79	111	1tdl	2.6	1tdl	1tdl
			18 Jun 79	111	1tdl	1tdl	1tdl	1tdl

* 1tdl = less than detectable limits

Table 10

Basin F Containment Hydrogeology Assessment, Comparison of Contaminants in Deep Borings with those in Adjacent Borings (Vicinity of DB-3)

Well No.	Formation	Elevation of Screen (ft)	Date	Chloride (ppm)	O-Sulfone (ppb)	DIMP (ppb)	Dithiane (ppb)	Oxathiane (ppb)
478	Alluvium	5139.0-5135.0	5 Mar 79	2620	91.2	823	25.9	7.4
			23 Apr 79	852	37.7	365	8.1	ltdl*
			24 Apr 79	712	21.6	308	6.9	ltdl
480	Alluvium	5138.5-5134.5	24 Apr 79	1245	35.2	713	27.8	6.6
DB-3-1		5101.6-5081.6	5 Apr 79	54	ltdl	ltdl	ltdl	ltdl
			17 Apr 79	56	ltdl	ltdl	ltdl	ltdl
			5 Jun 79	57	ltdl	2.3	ltdl	ltdl
			18 Jun 79	53	ltdl	ltdl	ltdl	ltdl
DB-3-2		5058.6-5033.6	5 Apr 79	68	ltdl	ltdl	ltdl	ltdl
			17 Apr 79	74	ltdl	ltdl	ltdl	ltdl
			5 Jun 79	70	ltdl	2.4	ltdl	ltdl
			18 Jun 79	68	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

Table 11

Basin F Containment Hydrogeology Assessment, Comparison of Contaminants in Deep Borings with those in Adjacent Borings (Vicinity of DB-4)

Well No.	Formation	Elevation of Screen (ft)	Date	Chloride (ppm)	O-Sulfone (ppb)	DIMP (ppb)	Dithiane (ppb)	Oxathiane (ppb)
458	Denver	5132.5-5128.5	13 Dec 78	580	ltdl*	3240	0.45	ltdl
			1 Feb 79	603	ltdl	420	ltdl	ltdl
			25 Apr 79	613	ltdl	451	ltdl	ltdl
491	Denver	5163.1-5159.1	3 Jan 79	168	ltdl	9.25	ltdl	ltdl
			12 Mar 79	136	ltdl	5.1	ltdl	ltdl
			12 Mar 79	177	13	19.7	ltdl	ltdl
			29 Mar 79	157	ltdl	13.1	ltdl	ltdl
			23 Apr 79	175	11.5	19.9	17.6	ltdl
464	Denver	5145.2-5141.2	23 Apr 79	294	10	312	ltdl	ltdl
DB-4-1		5162.2-5143.6	17 Apr 79	56	ltdl	ltdl	ltdl	ltdl
			30 Apr 79	984	ltdl	48.8	ltdl	ltdl
			5 Jun 79	801	ltdl	107.0	ltdl	ltdl
			18 Jun 79	826	ltdl	113.3	ltdl	ltdl
DB-4-2		5124.6-5094.6	17 Apr 79	144	ltdl	ltdl	ltdl	ltdl
			5 Jun 79	44	ltdl	2.8	ltdl	ltdl
			18 Jun 79	44	ltdl	ltdl	ltdl	ltdl
DB-4-3		5083.6-5075.6	17 Apr 79	36	ltdl	ltdl	ltdl	ltdl
			30 Apr 79	51	ltdl	ltdl	ltdl	ltdl
			5 Jun 79	24	ltdl	ltdl	ltdl	ltdl
			18 Jun 79	27	ltdl	ltdl	ltdl	ltdl

* ltdl = less than detectable limits

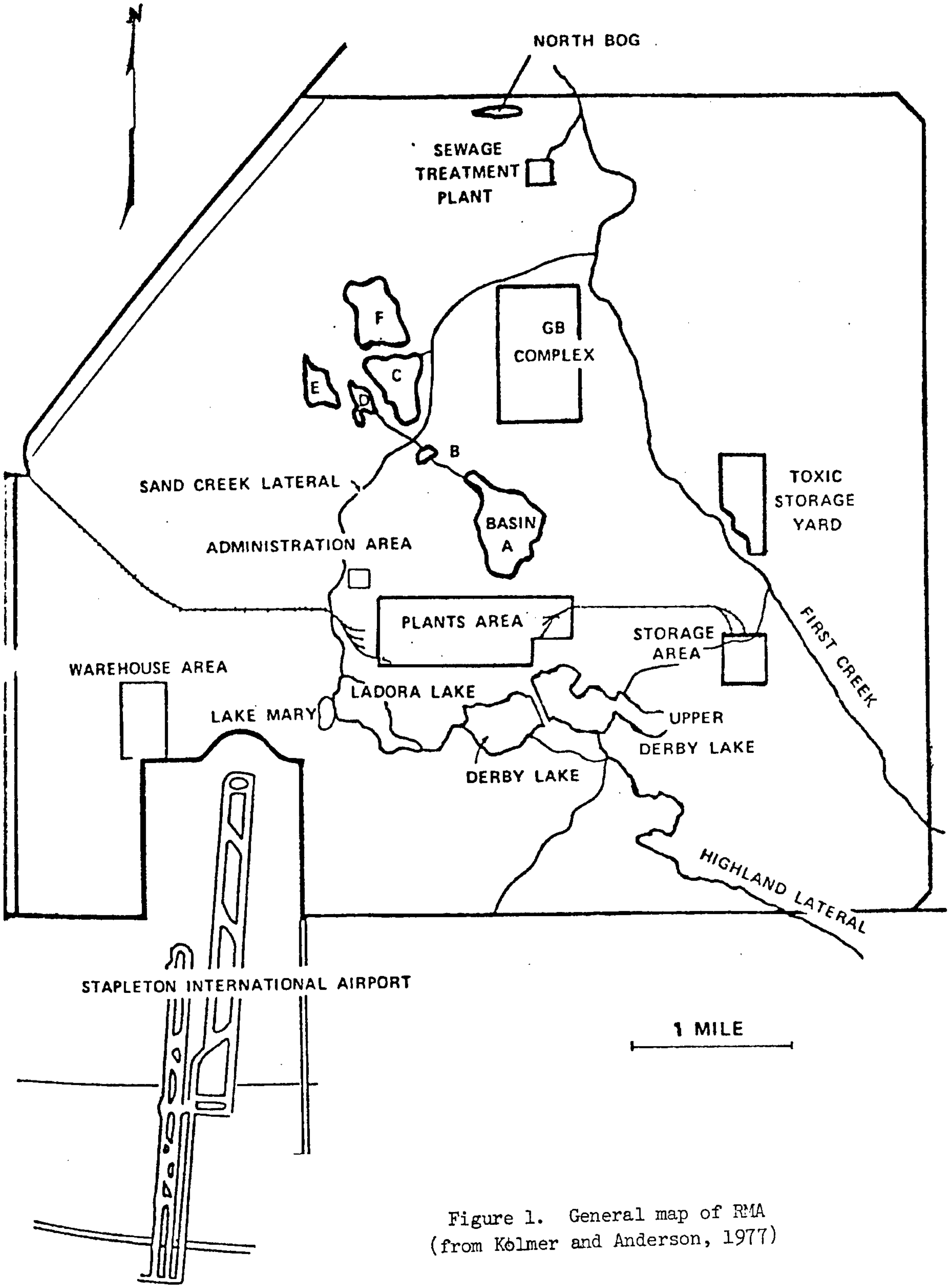


Figure 1. General map of RMA
(from Kolmer and Anderson, 1977)

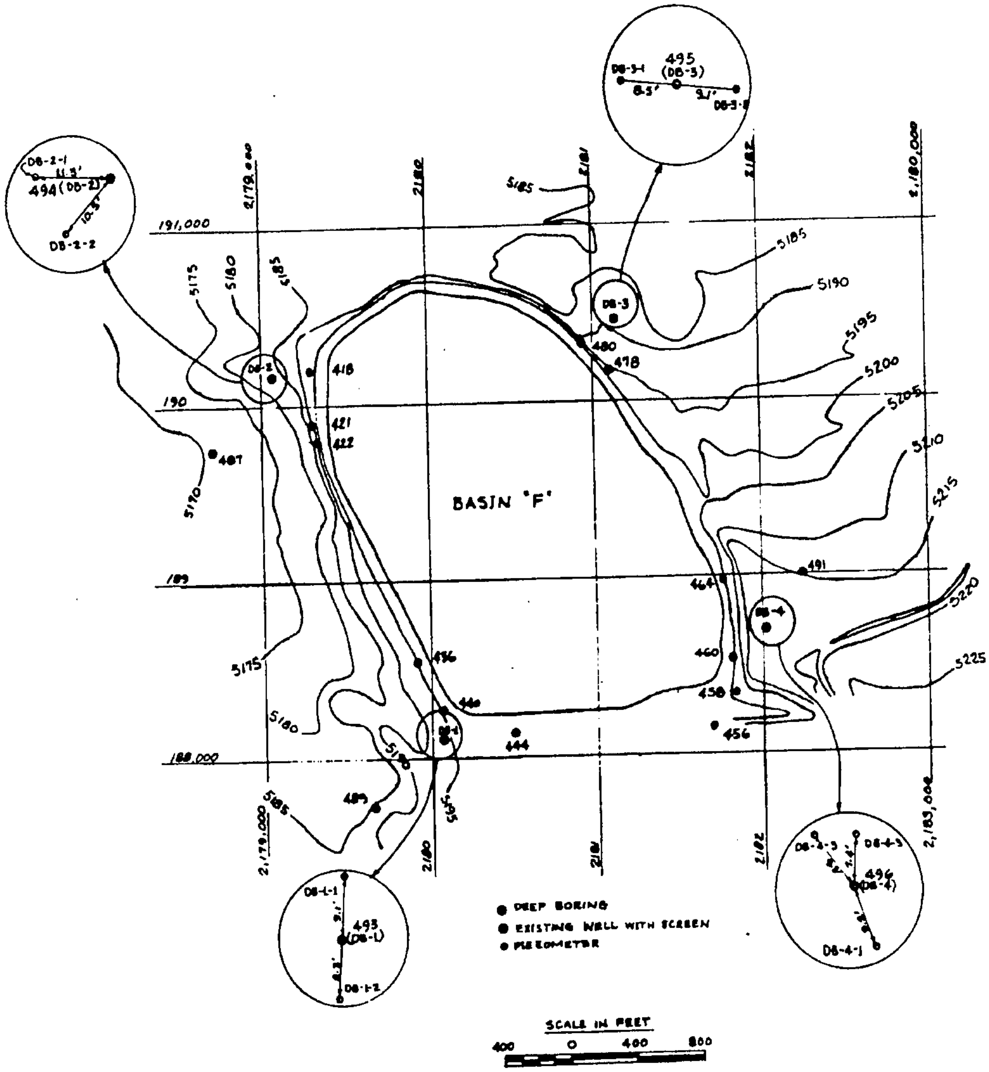


Figure 2. Locations of deep borings and associated shallow borings near basin F

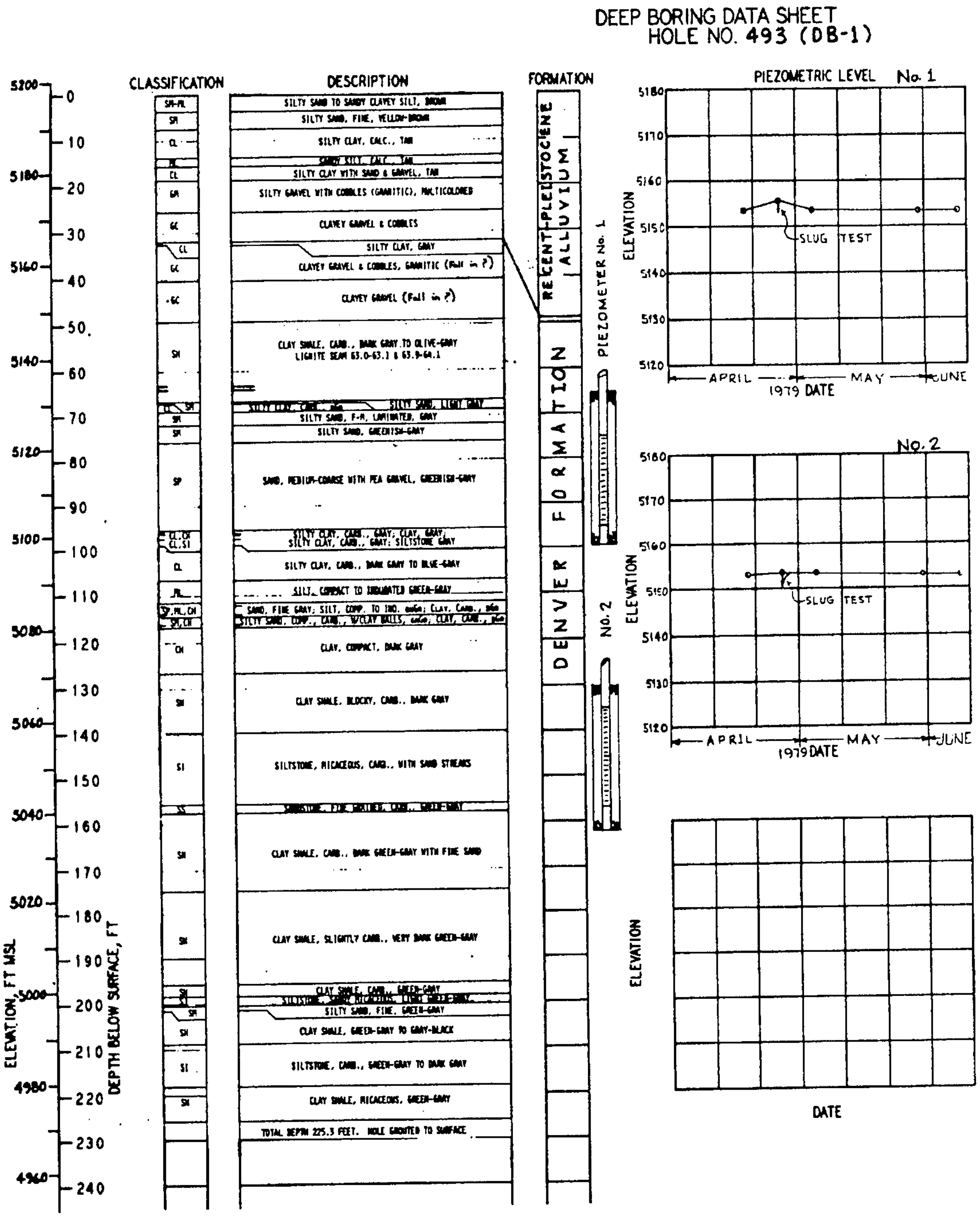


Figure 3. Boring log and water levels, DB-1

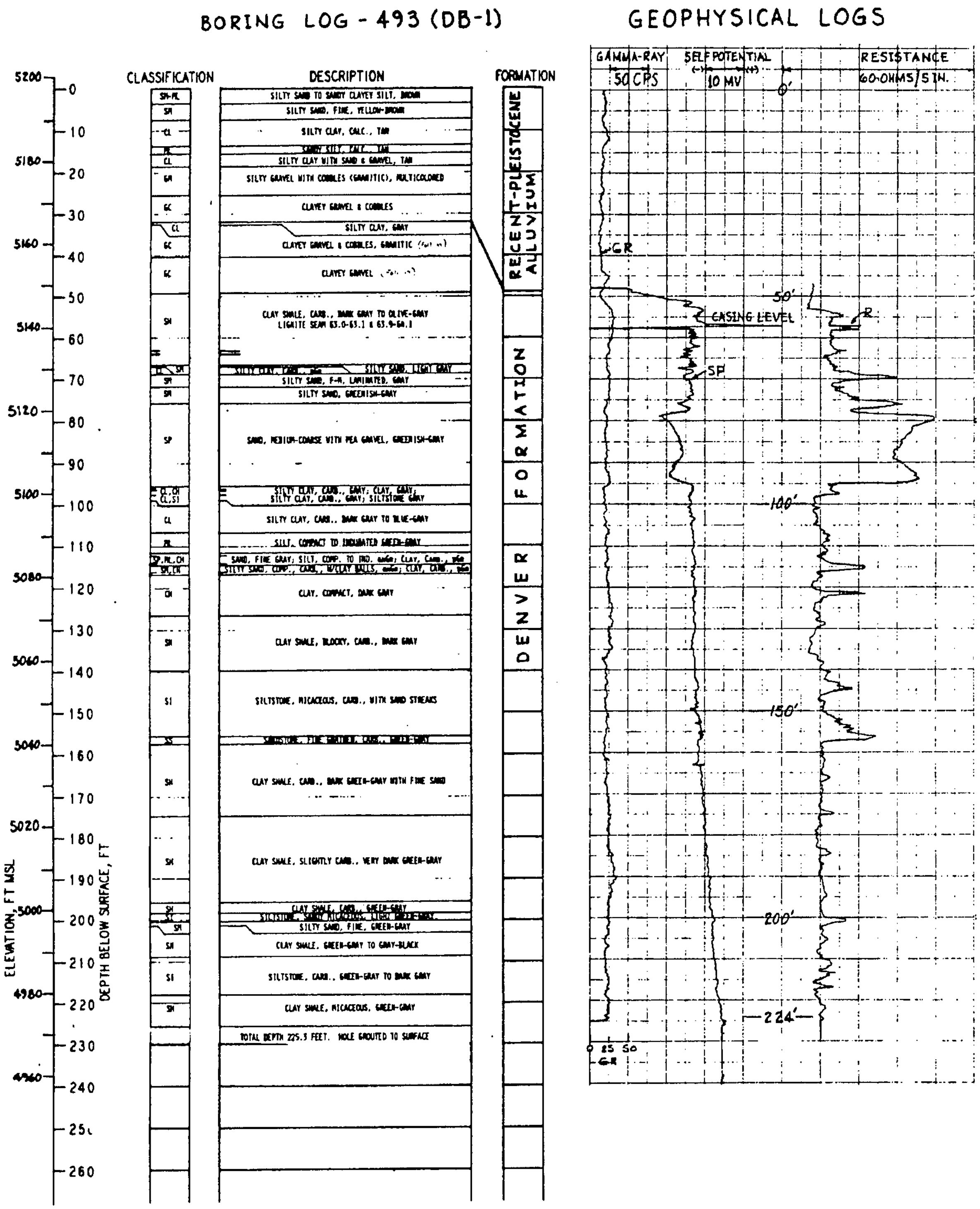


Figure 4. Boring log and g. :physical logs, DB-1

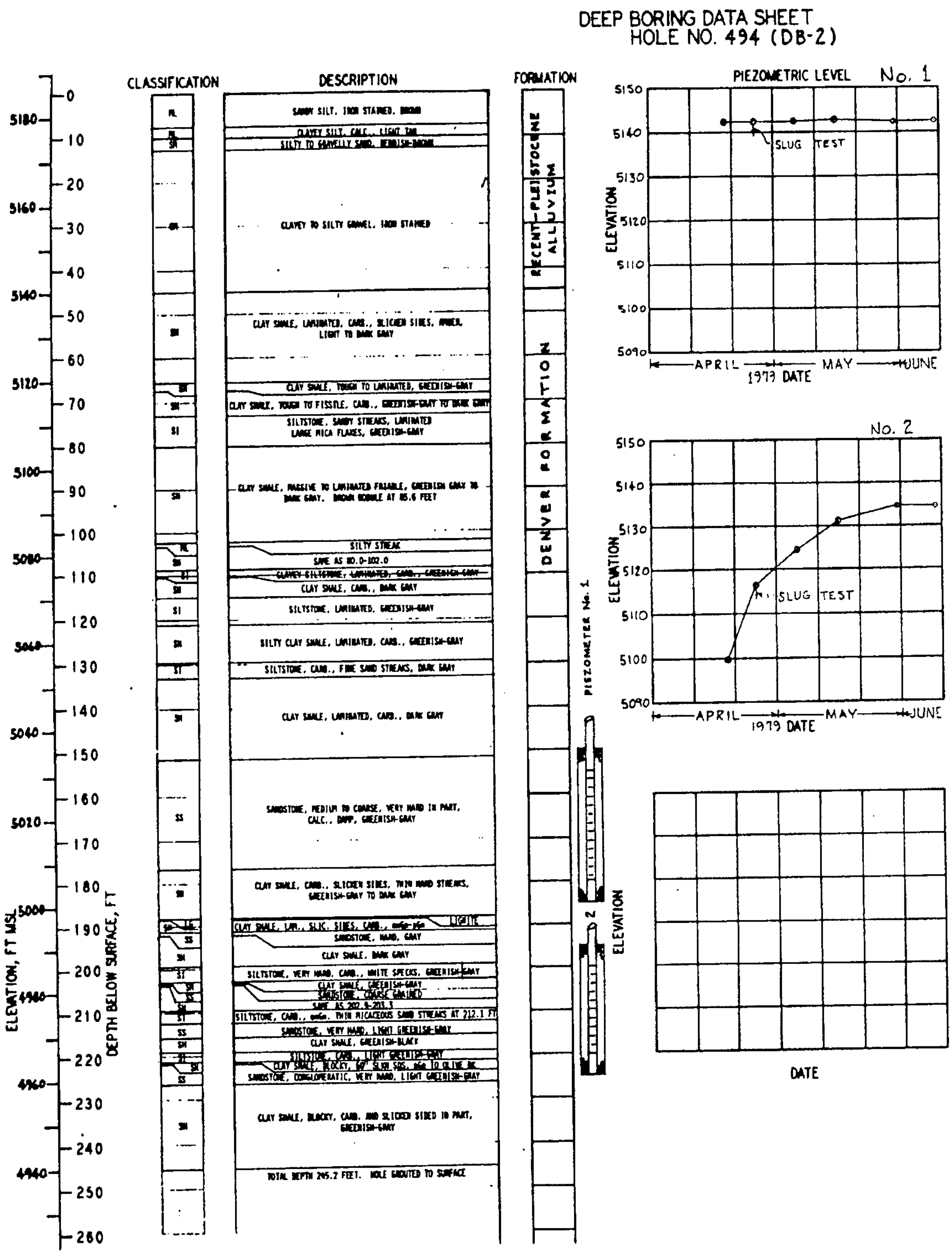


Figure 5. Boring log and water level, DB-2

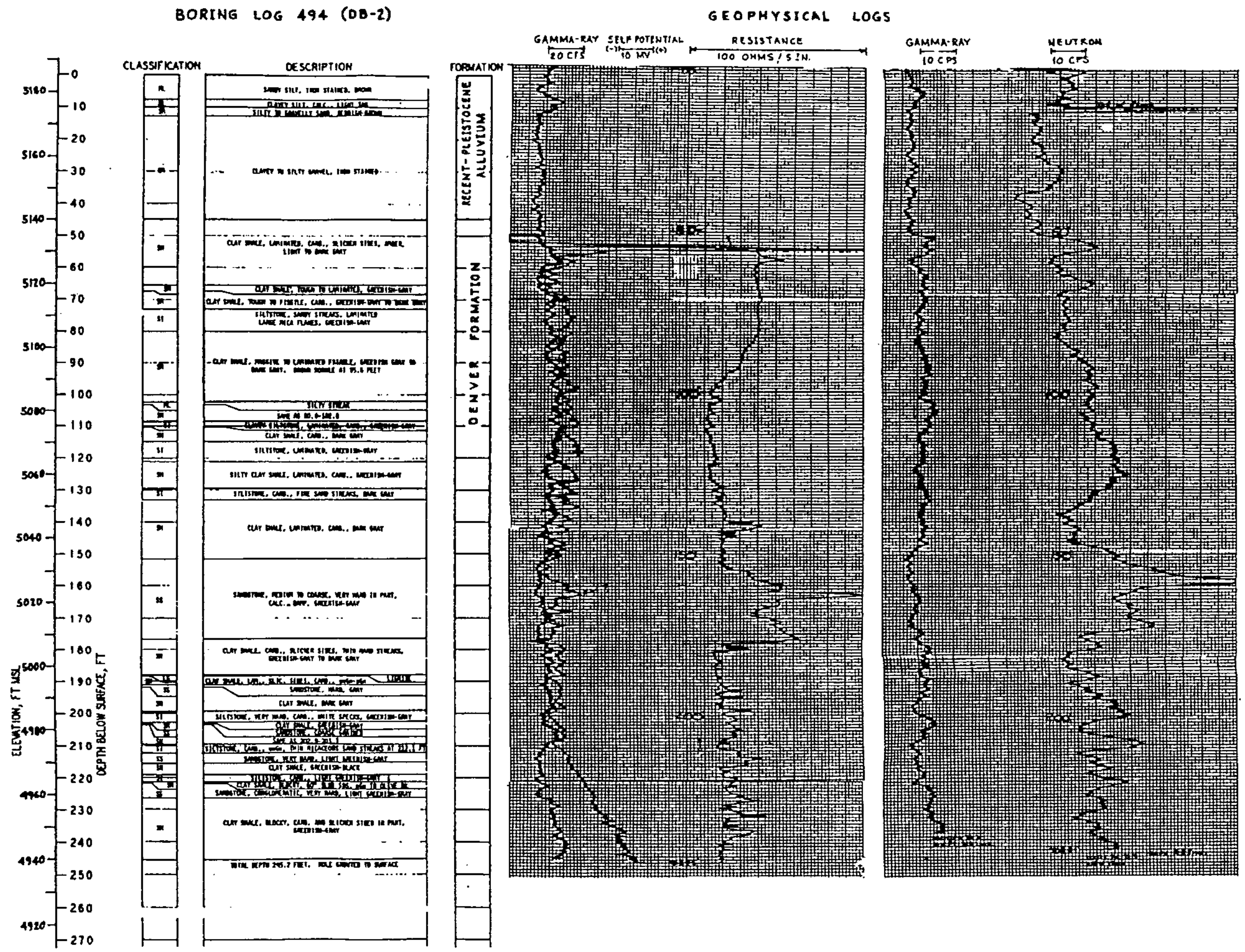


Figure 6. Boring log and geophysical logs, DB-2

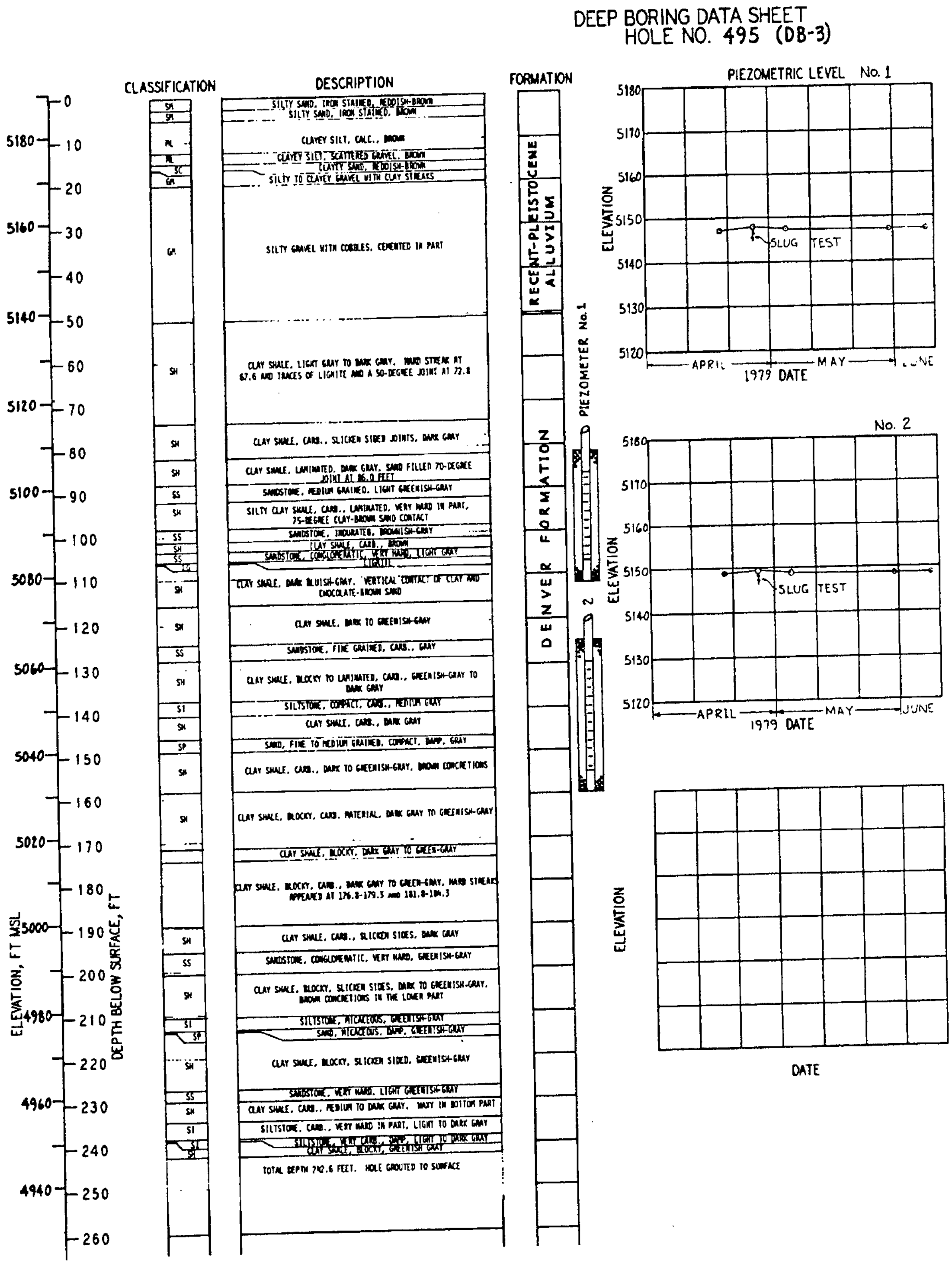


Figure 7. Boring log and water levels, DB-3

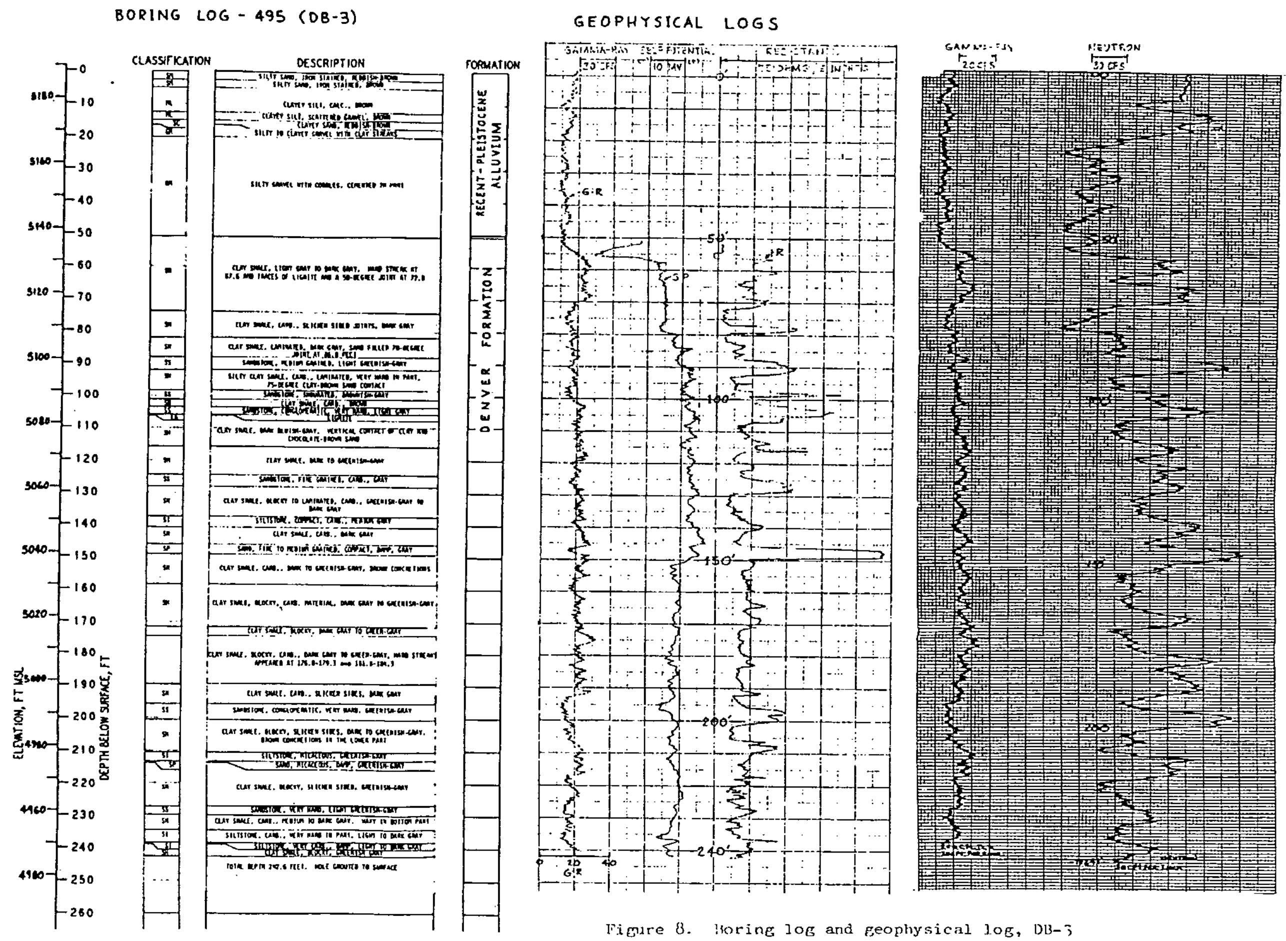


Figure 8. Boring log and geophysical log, DB-3

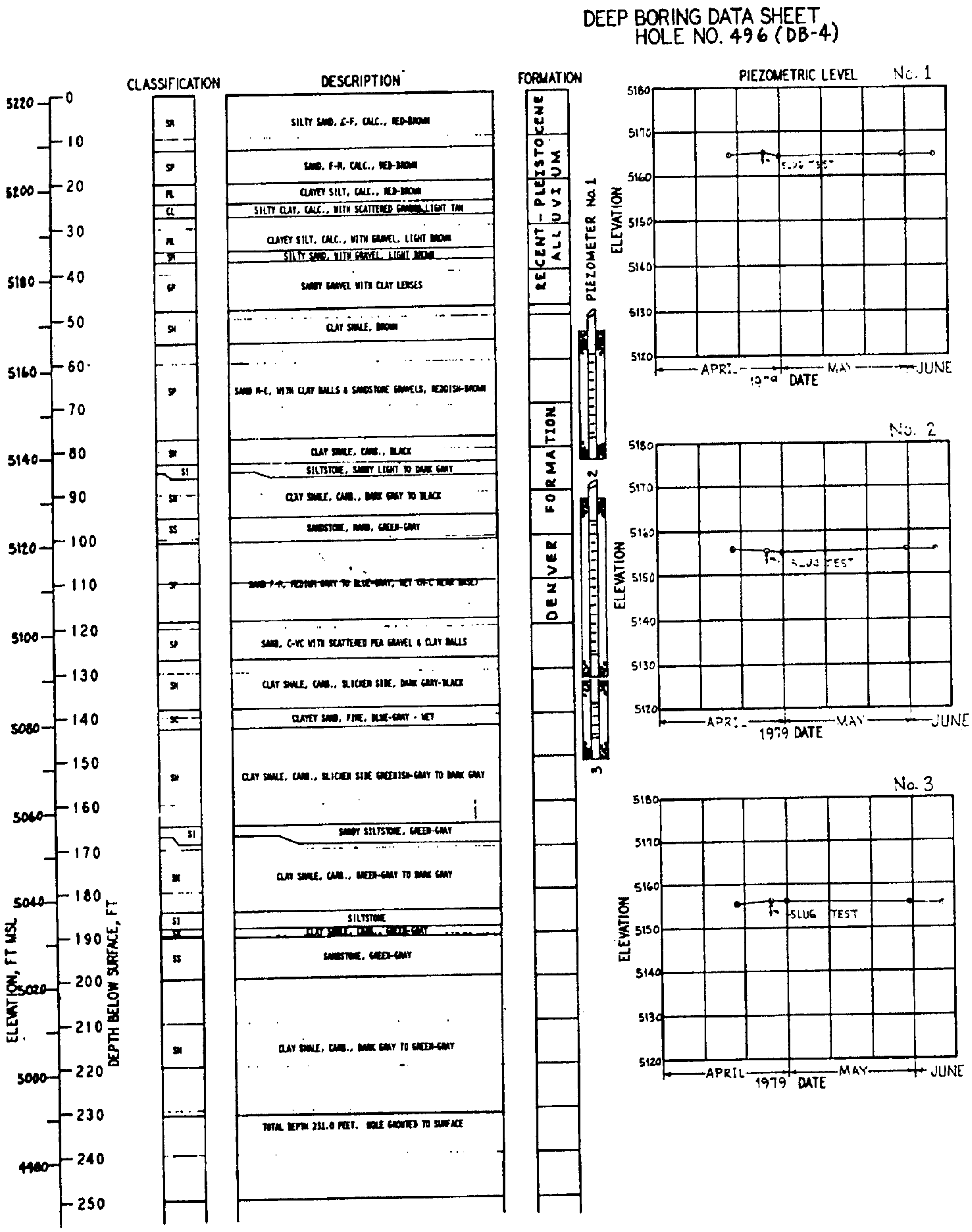


Figure 9. Boring log and water levels, DB-4

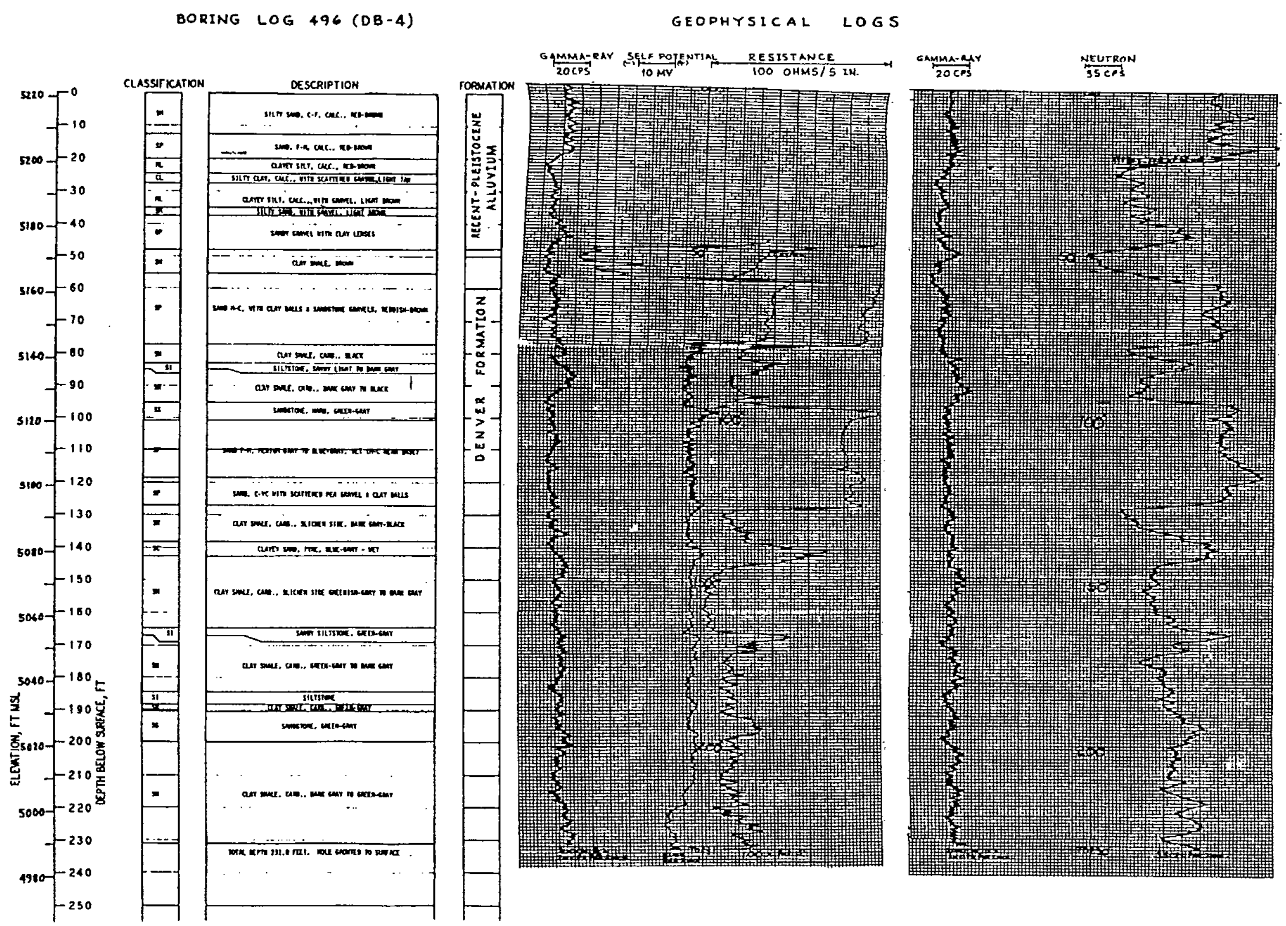


Figure 10. Boring log and geophysical logs, DB-4

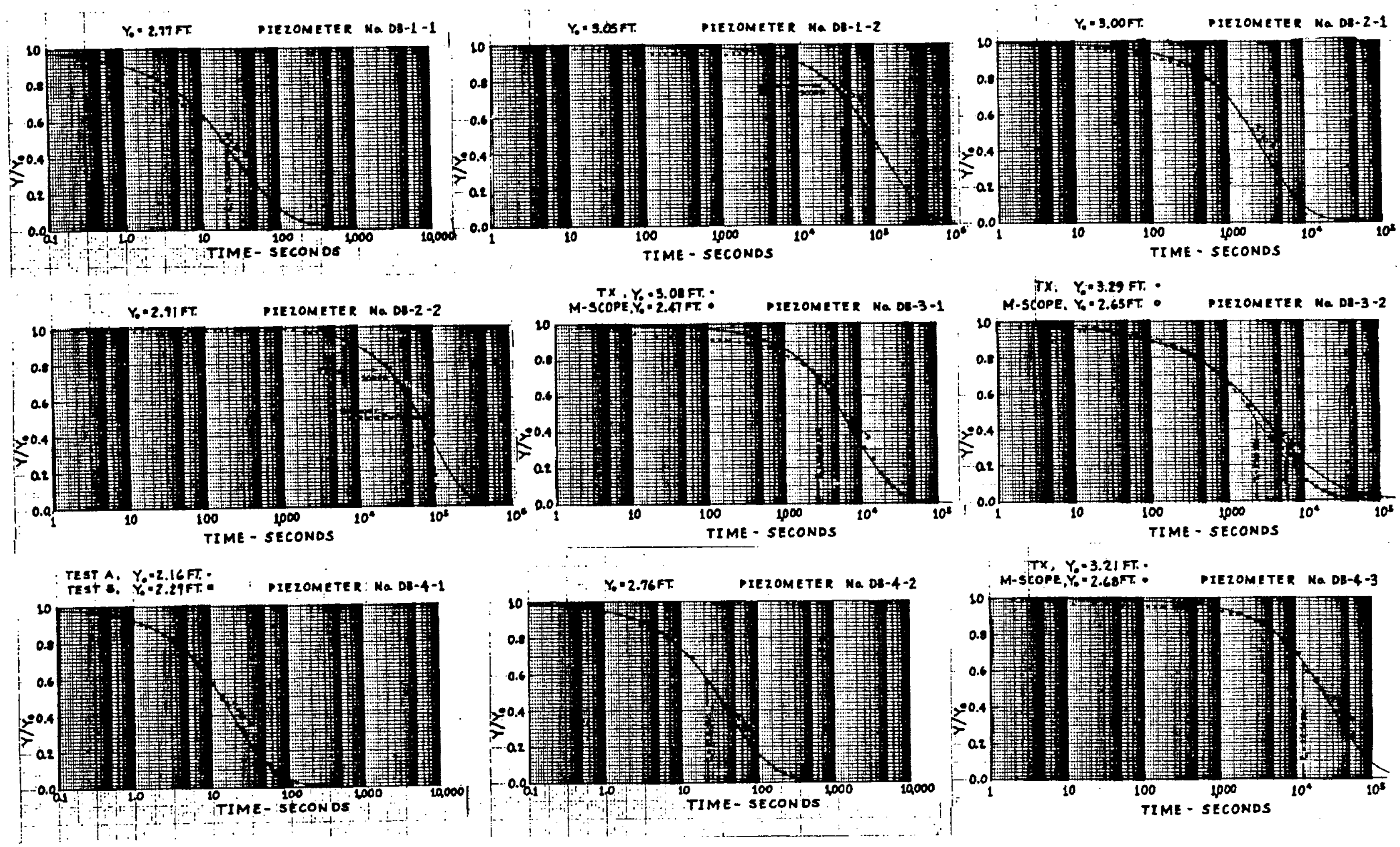
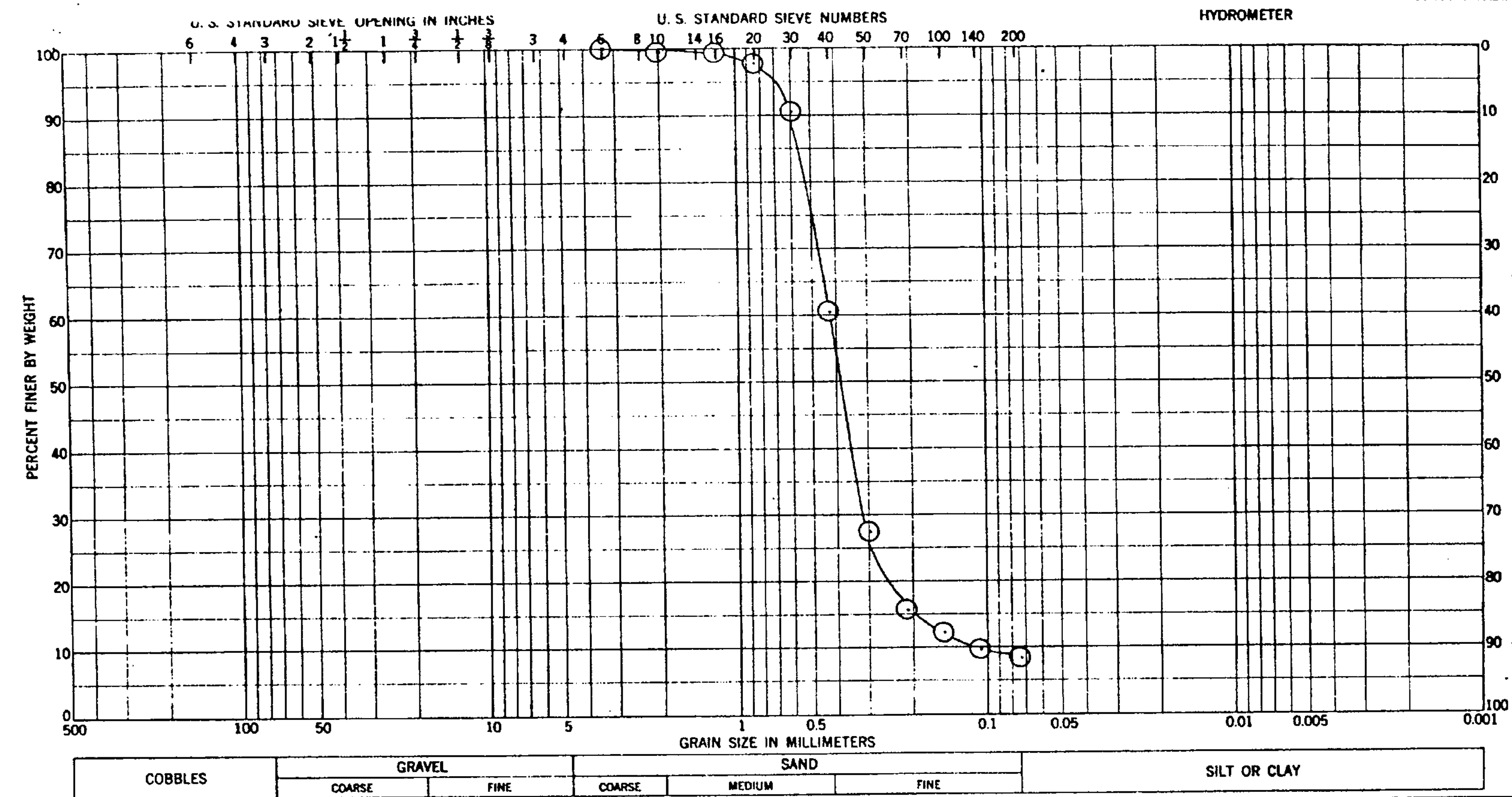


Figure 11. Change in water level with time-slug tests



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	79.0-81.5	SILTY SAND (SP-SM) GRAY				
		$K_{20} = 4.79 \times 10^{-4}$ cm./sec				

Project: ROCKY MOUNTAIN ARSENAL

Area:

Boring No. DB-1

Date: 29 JUNE 79

GRADATION CURVES

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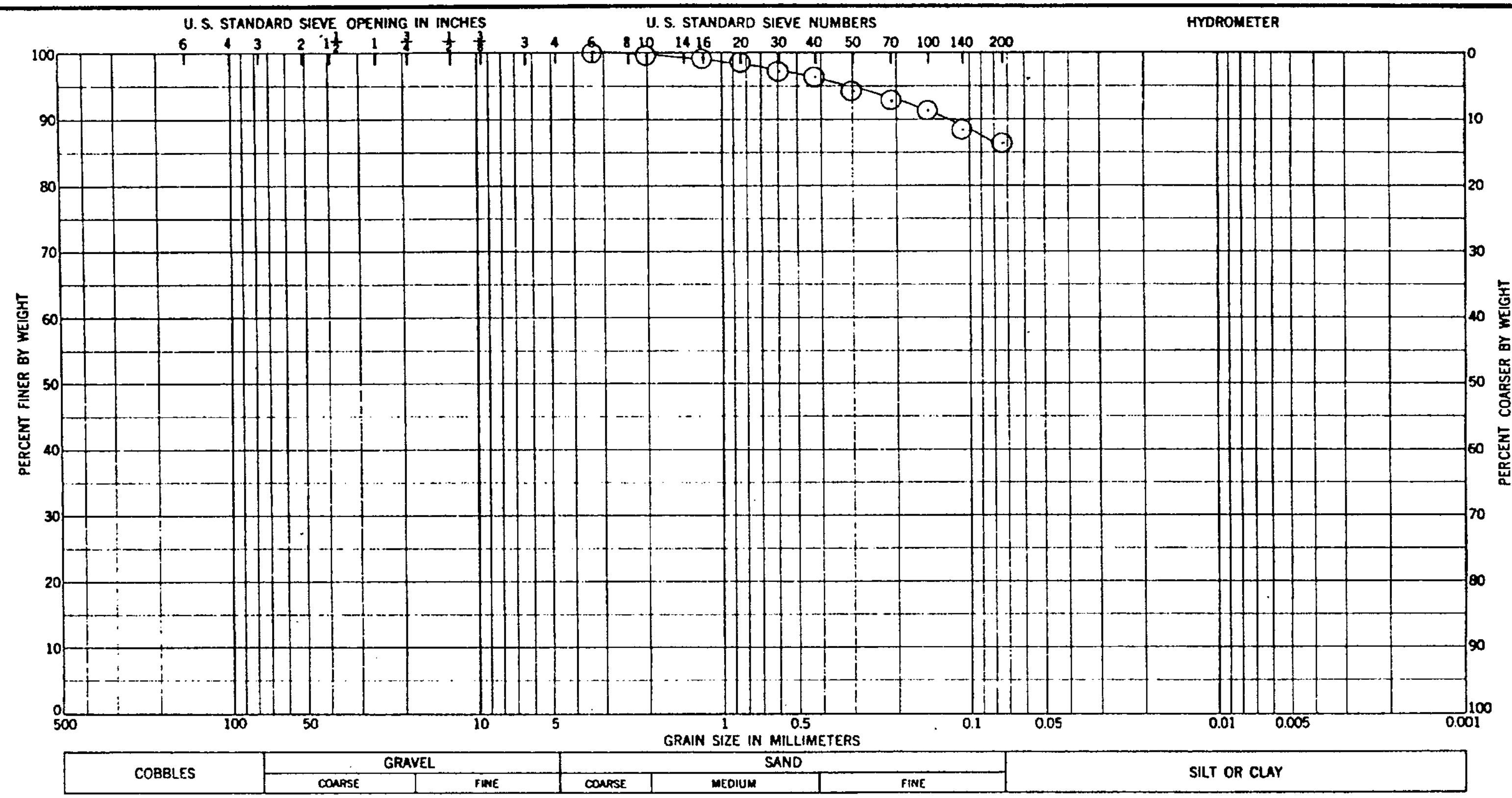
Figure 12. Gradation curve - boring DB-1-1



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
2	143.0-144.0	SANDY CLAY (CL) GRAY				
		$K_{20} = 3.08 \times 10^{-8}$ cm./sec				

Project ROCKY MOUNTAIN ARSENAL

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GRADATION CURVES

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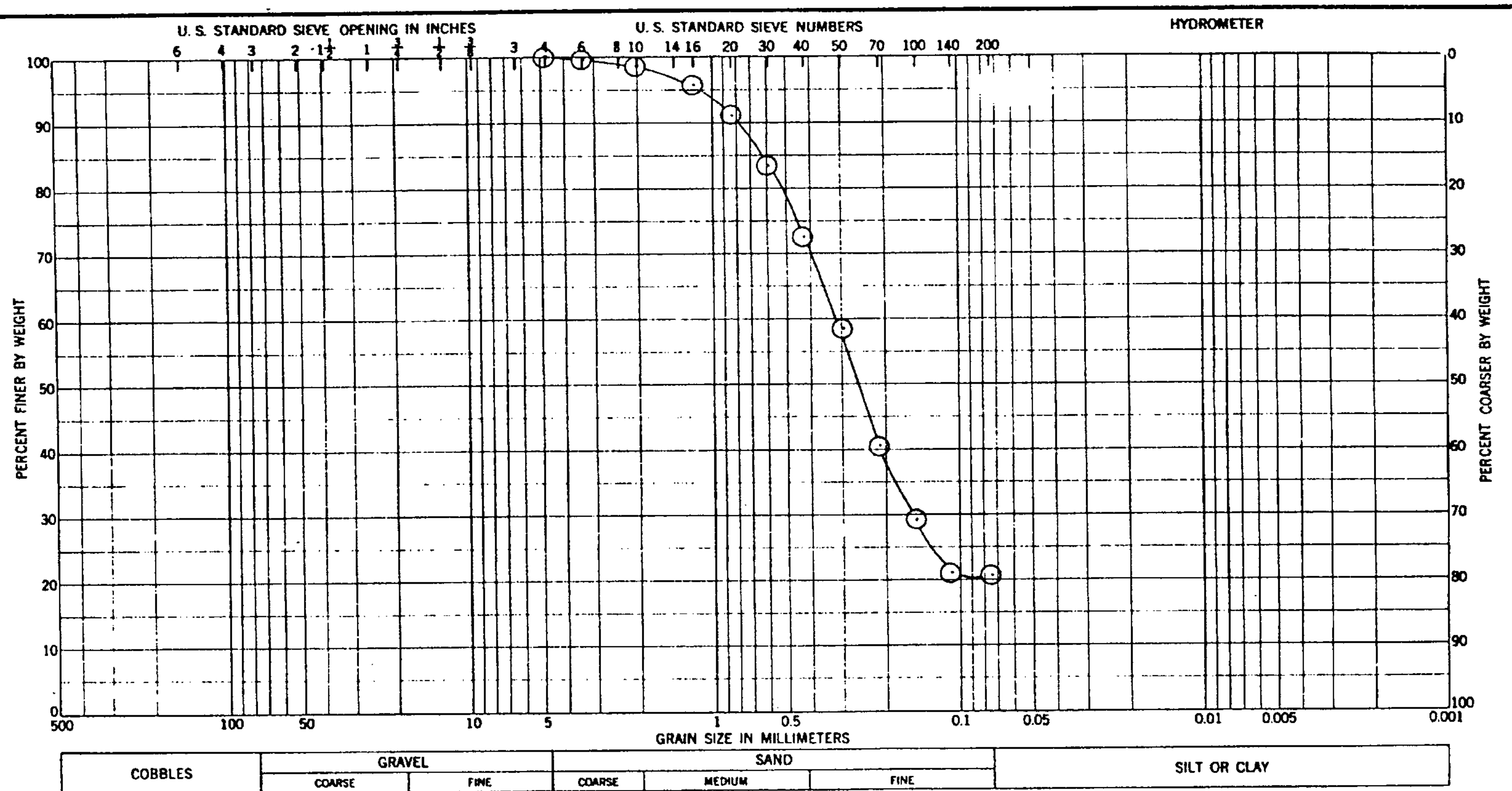
Figure 13. Gradation curve - boring DB-1-2



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	155.0-157.0	SILTY SAND (SM) BROWN				
		SAMPLE CONTAINED SEVERAL				
		LARGE GRAVEL SIZED SANDSTONE				
		NOT INCLUDED IN GRADATION				
		$K_{20} = 1.07 \times 10^{-6}$ cm/sec				

Project ROCKY MOUNTAIN ARSENAL

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Boring No. DB-2

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GRADATION CURVES

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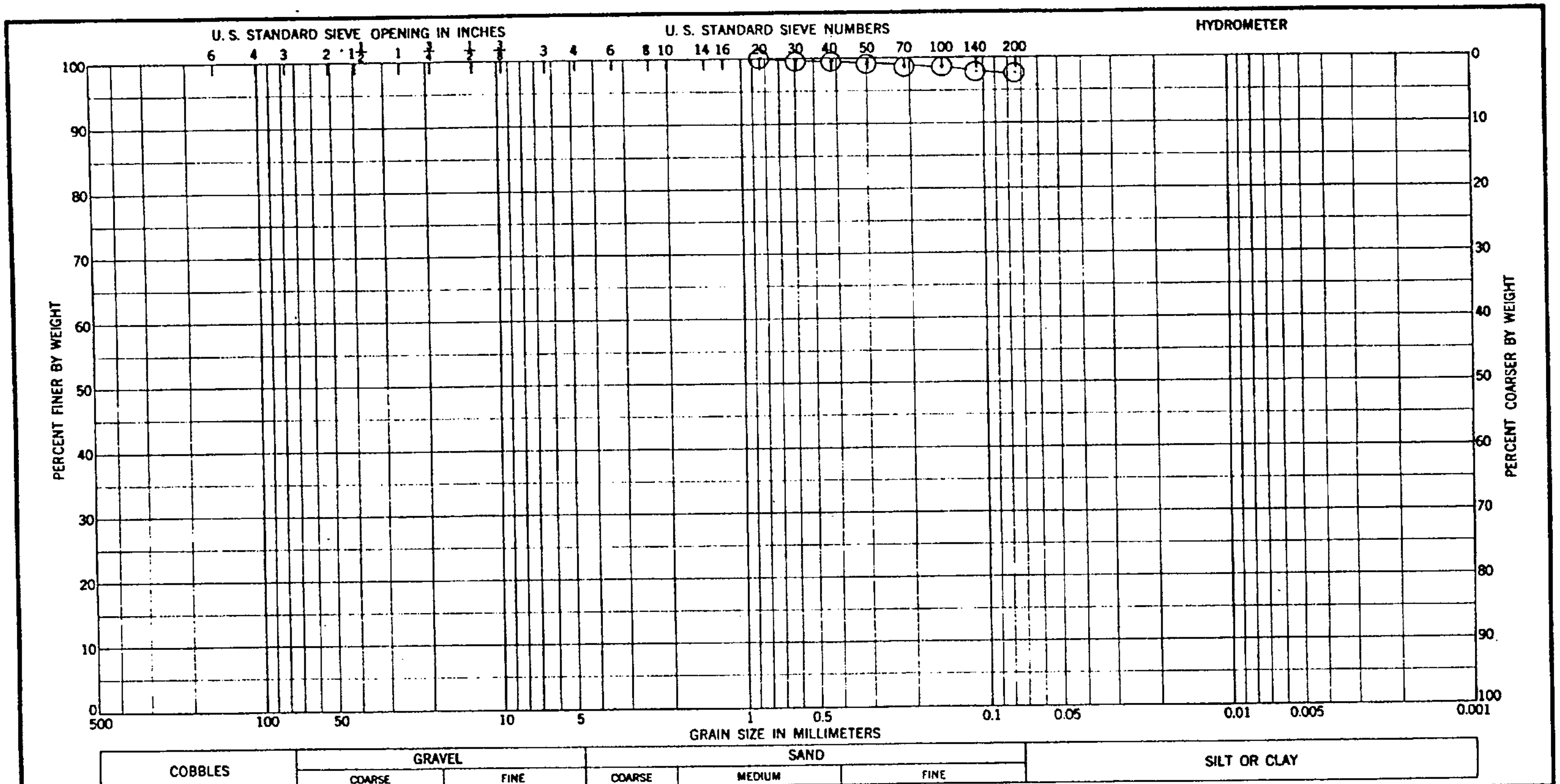
Figure 14. Gradation curve - boring DB-2-1



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
2	212.0-214.5	CLAY (CH) GRAY				
		$K_{20} = 5.82 \times 10^{-7}$ cm./sec.				

Project ROCKY MOUNTAIN ARSENAL

Area

Boring No. DB-2

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GRADATION CURVES

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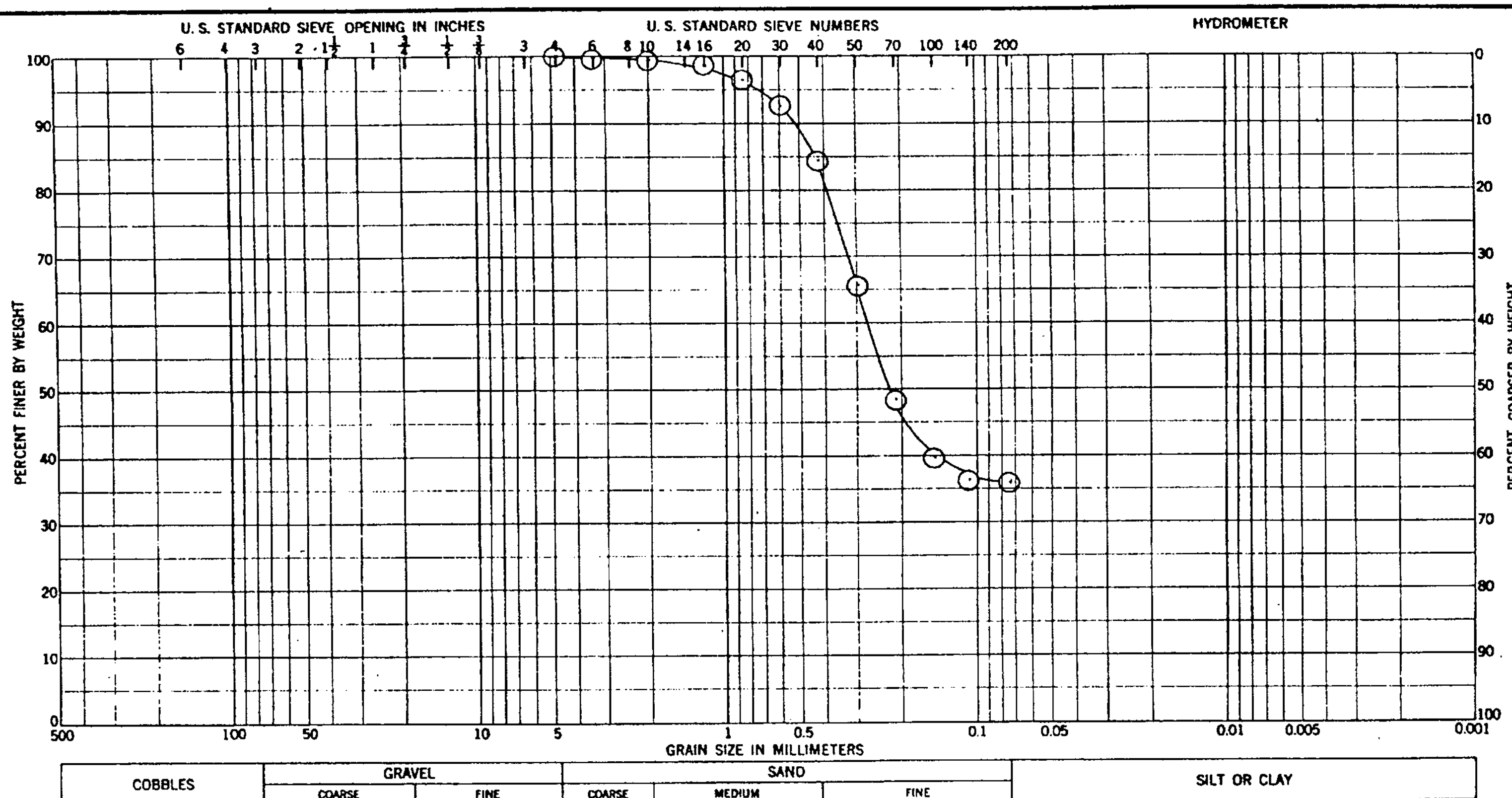
Figure 15. Gradation curve - boring DB-2-2



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	87.0-89.5	SILTY SAND (SM) GRAY				
		SAMPLE CONTAINED SEVERAL				
		LARGE GRAVEL SIZED SANDSTONE				
		NOT INCLUDED IN GRADATION				
		$K_{20} = 1.26 \times 10^{-5}$ cm./sec.				

Project: ROCKY MOUNTAIN ARSENAL

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GRADATION CURVES

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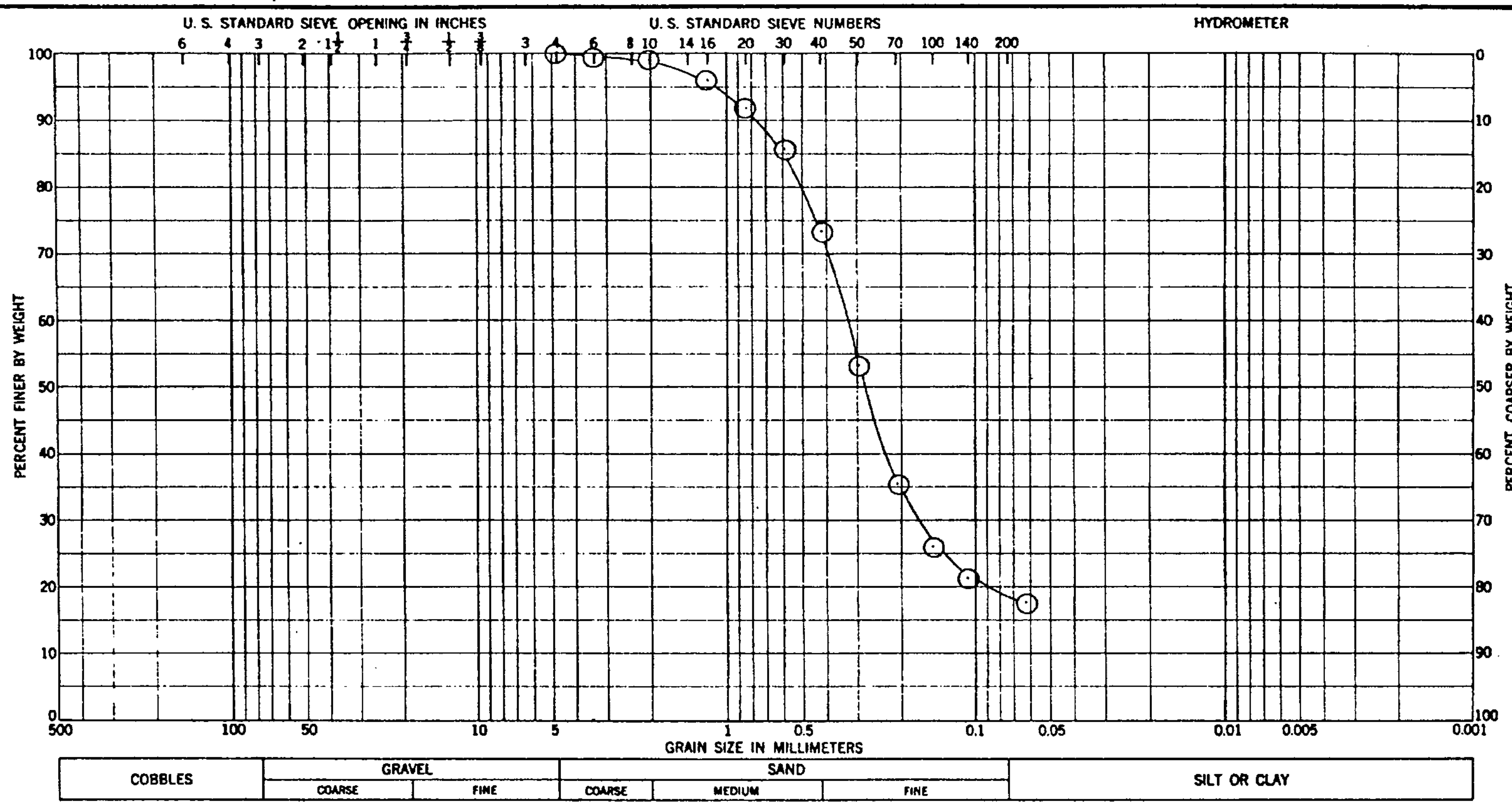
Figure 16a. Gradation curve - boring DB-3-1 (sheet 1 of 2)



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	89.5-90.0	SILTY SAND (SM) BROWN				
		SAMPLE CONTAINED SEVERAL LARGE GRAVEL SIZED SANDSTONE NOT INCLUDED IN GRADATION				
		$K_{20} = 7.88 \times 10^{-5}$ cm./sec.				

Project: ROCKY MOUNTAIN ARSENAL

Area:

Boring No.: DB-3

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GRADATION CURVES

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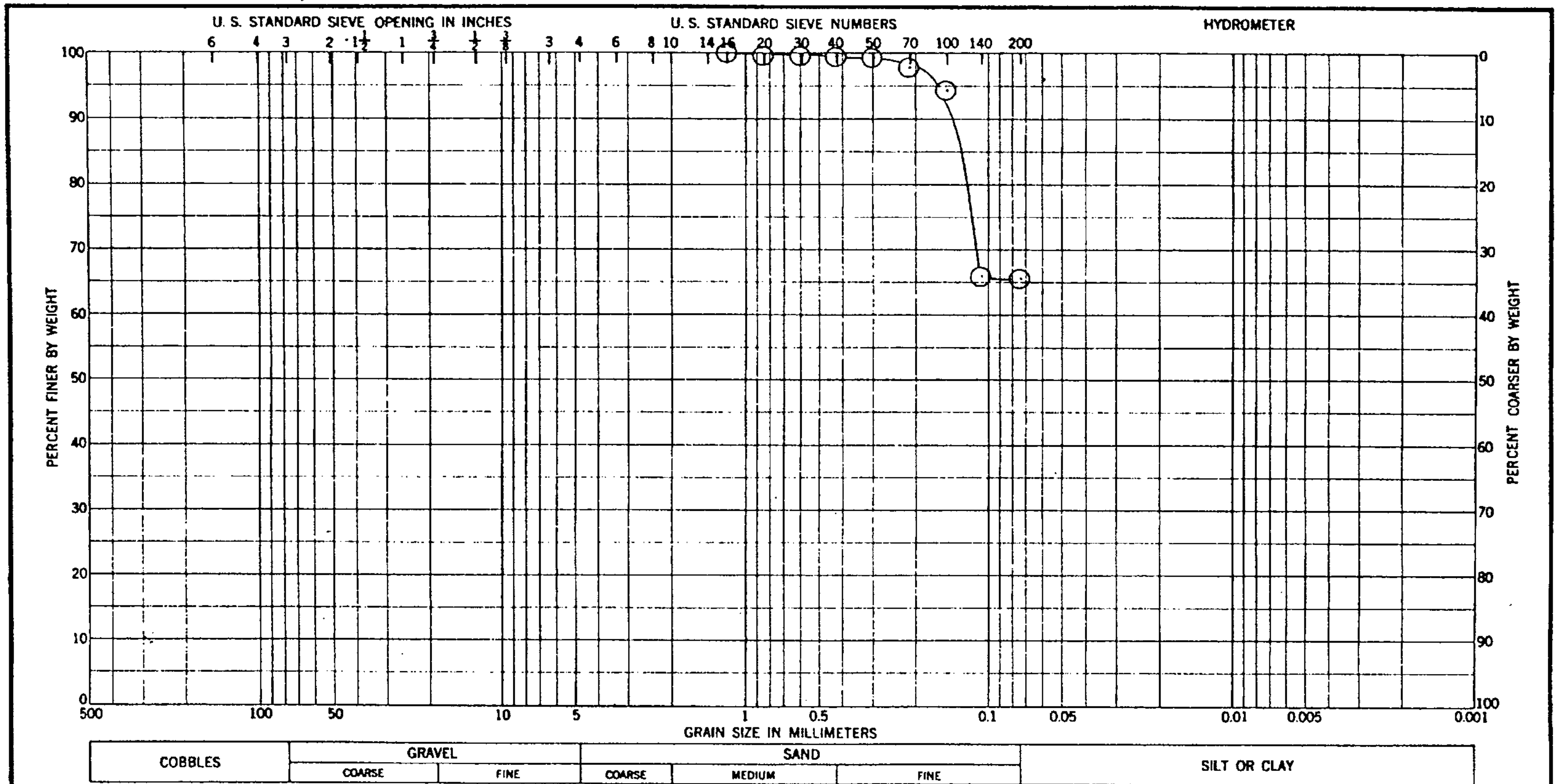
Figure 16b. (sheet 2 of 2)



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
2	146.0-148.5	SANDY SILT (ML) GRAY				
		$K_{20} = 1.45 \times 10^{-4}$ cm./sec.				

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GRADATION CURVES

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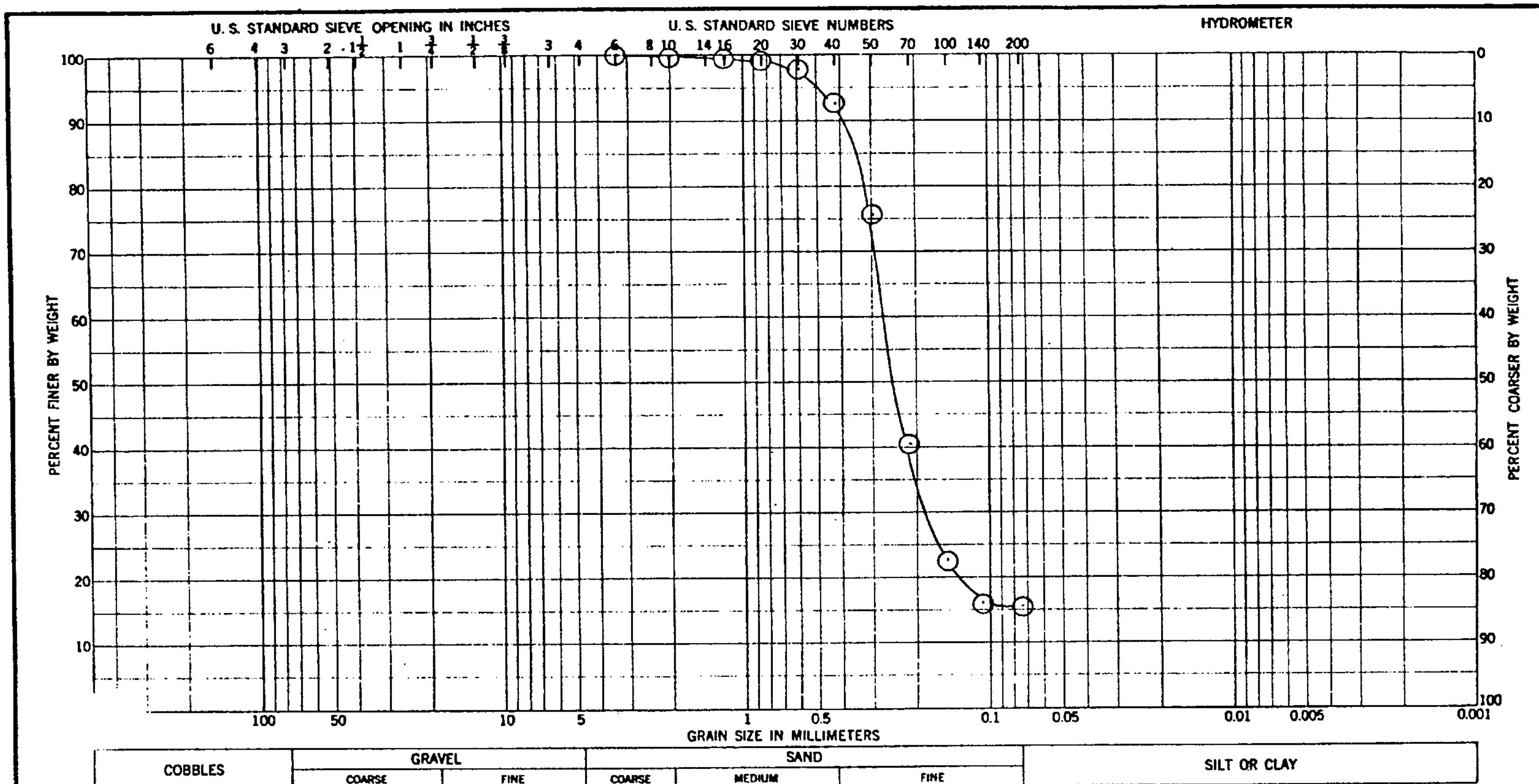
Figure 17. Gradation curve - boring DB-3-2



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1	60.0-62.0	SILTY SAND (SM) BROWN				
		$K_{20} = 4.20 \times 10^{-4}$ cm/sec.				

Project ROCKY MOUNTAIN ARSENAL

Area

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GRADATION CURVES

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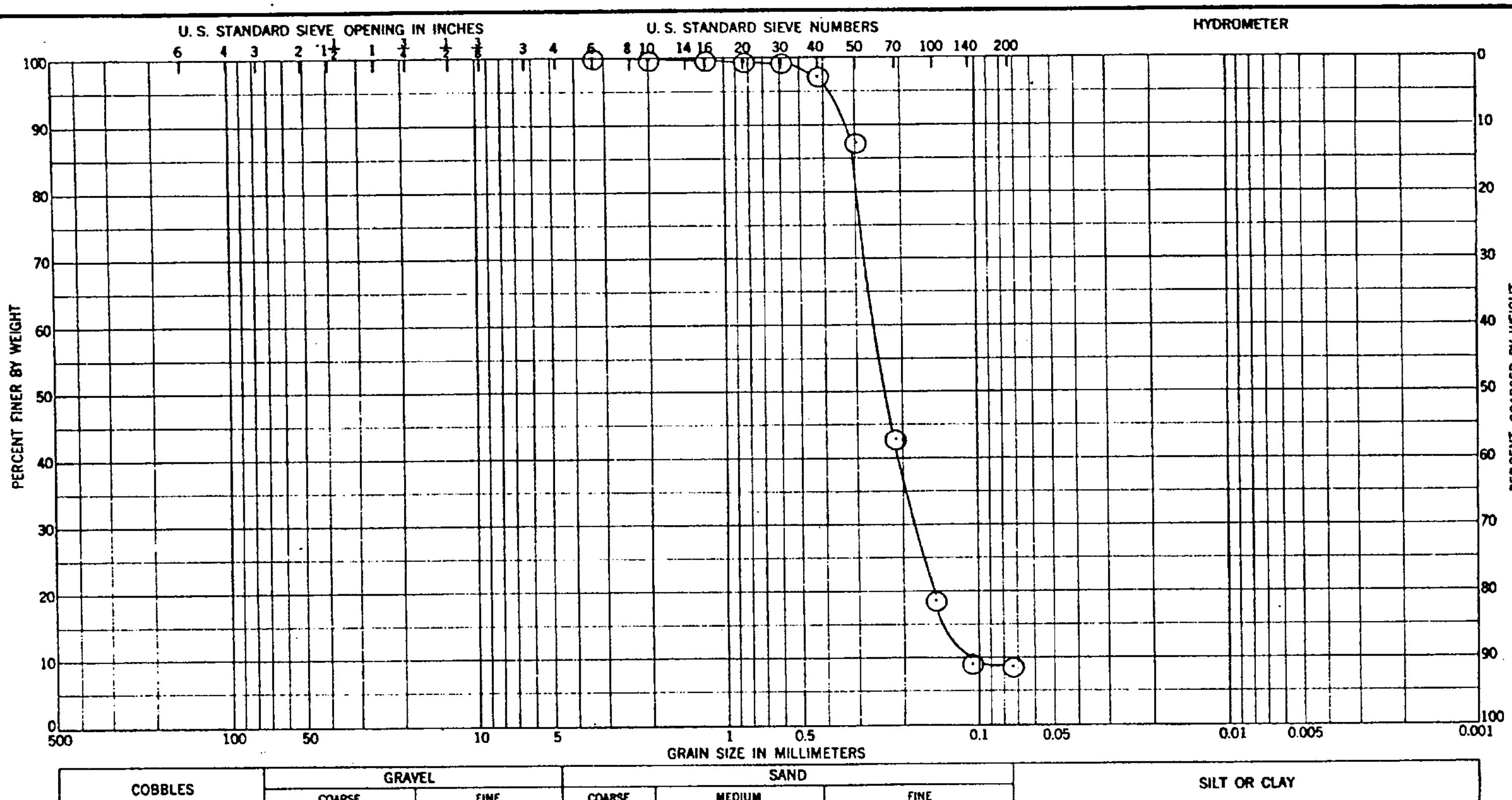
Figure 18. Gradation curve - boring DB-4-1



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
2	100.0-102.5	SILTY SAND (SP-SM) GRAY				
		$K_{20} = 1.27 \times 10^{-4}$ cm./sec.				

Project ROCKY MOUNTAIN ARSENAL

Area

Boring No. DB-4

Date 29 JUNE 79

GRADATION CURVES

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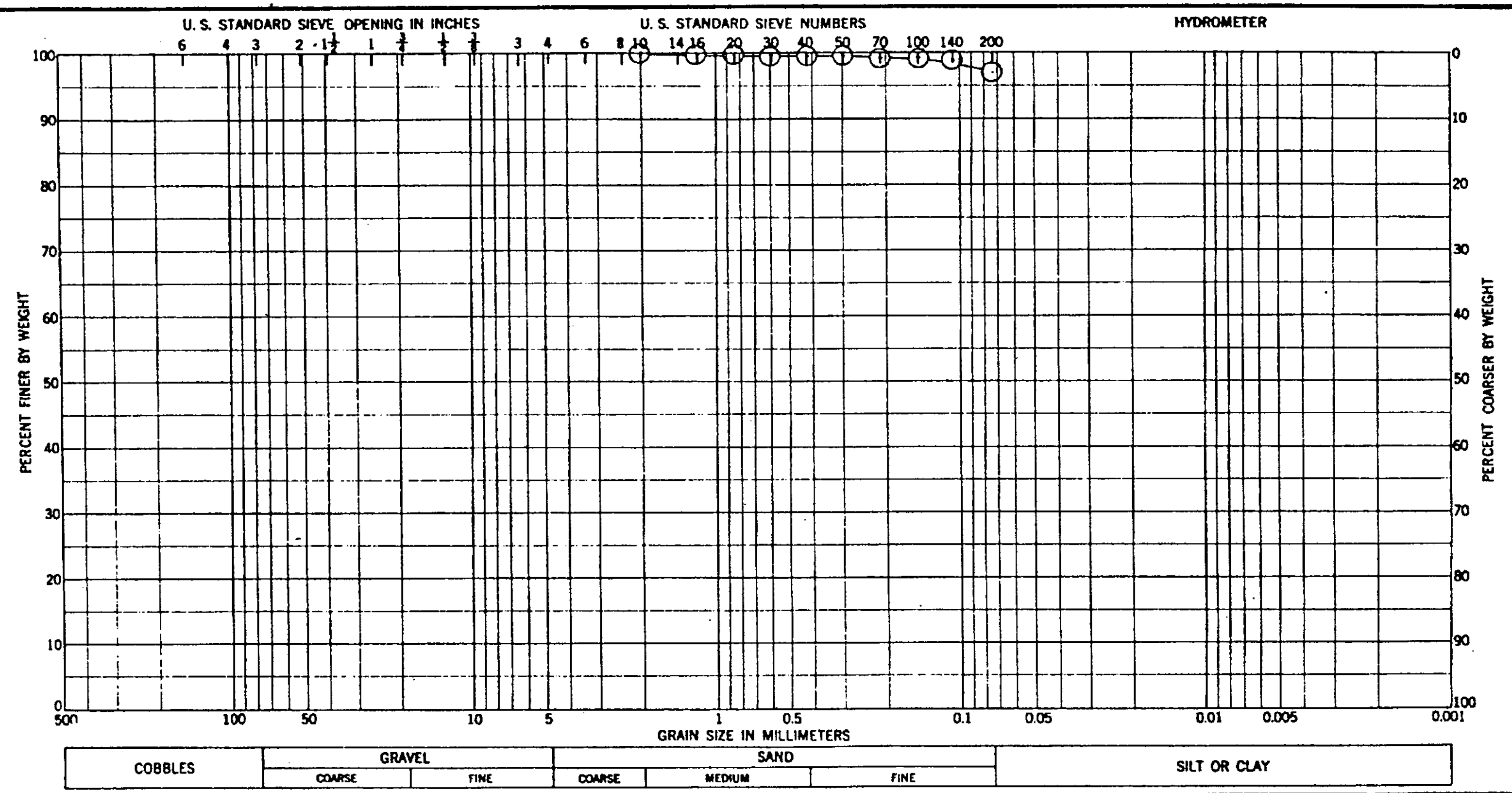
Figure 19. Gradation curve - boring DB-4-2



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
3	138.0-140.2	CLAY (CH) GRAY				
		$K_{20} = 6.44 \times 10^{-6}$ cm./sec.				

Project	ROCKY MOUNTAIN ARSENAL
Area	
Boring No.	DB-4
Date	29 JUNE 79

GRADATION CURVES

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Figure 20. Gradation curve - boring DB-4-3

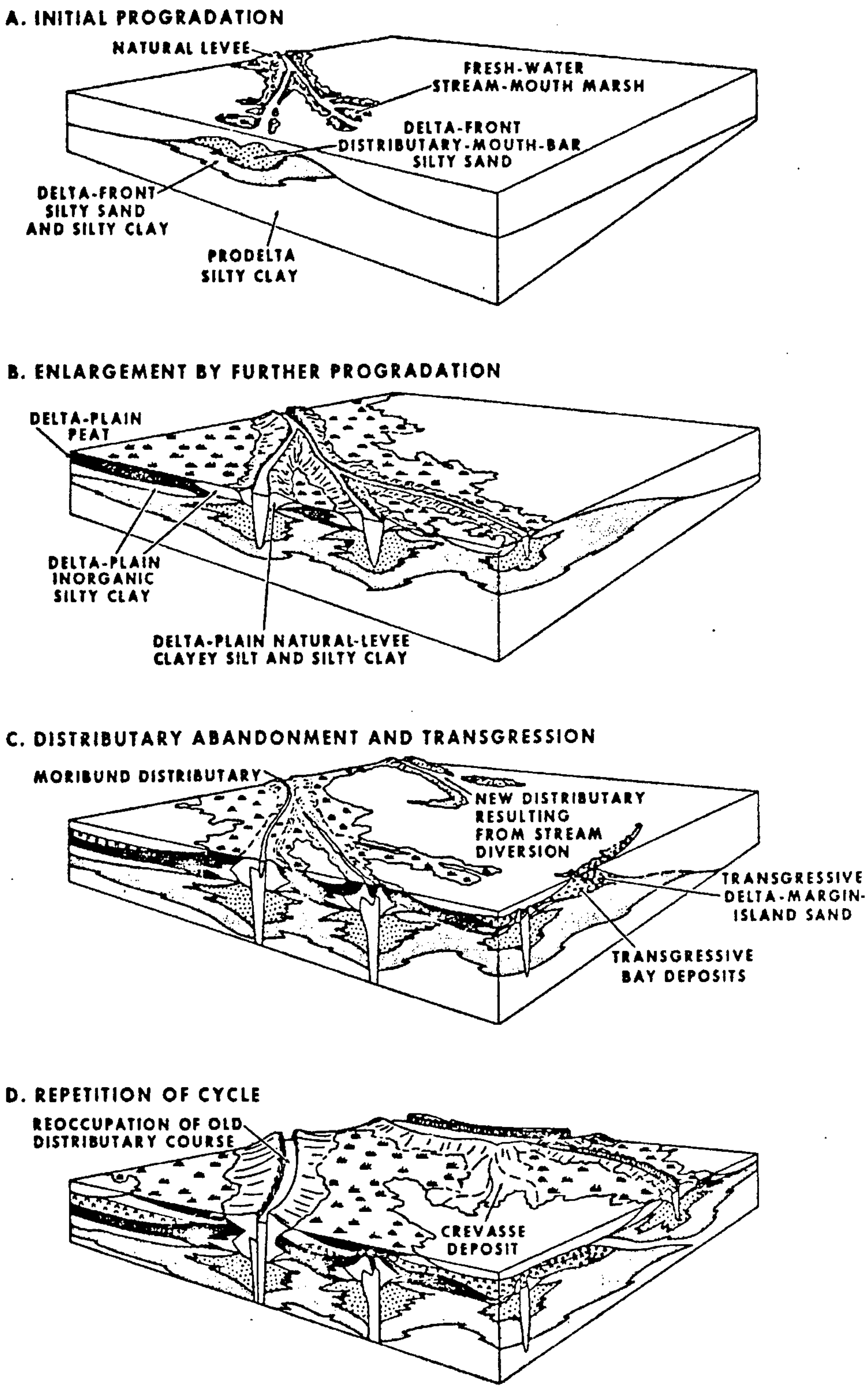

Figure 21. Deltaic environments of deposition
(from Frazier and Osanik, 1969)

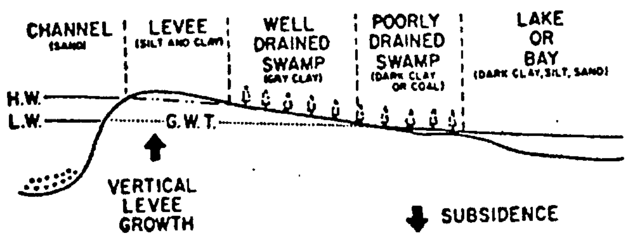

Figure 22. Environments of deposition and processes
occurring in channel--channel margin areas
(after Weimer, 1973)

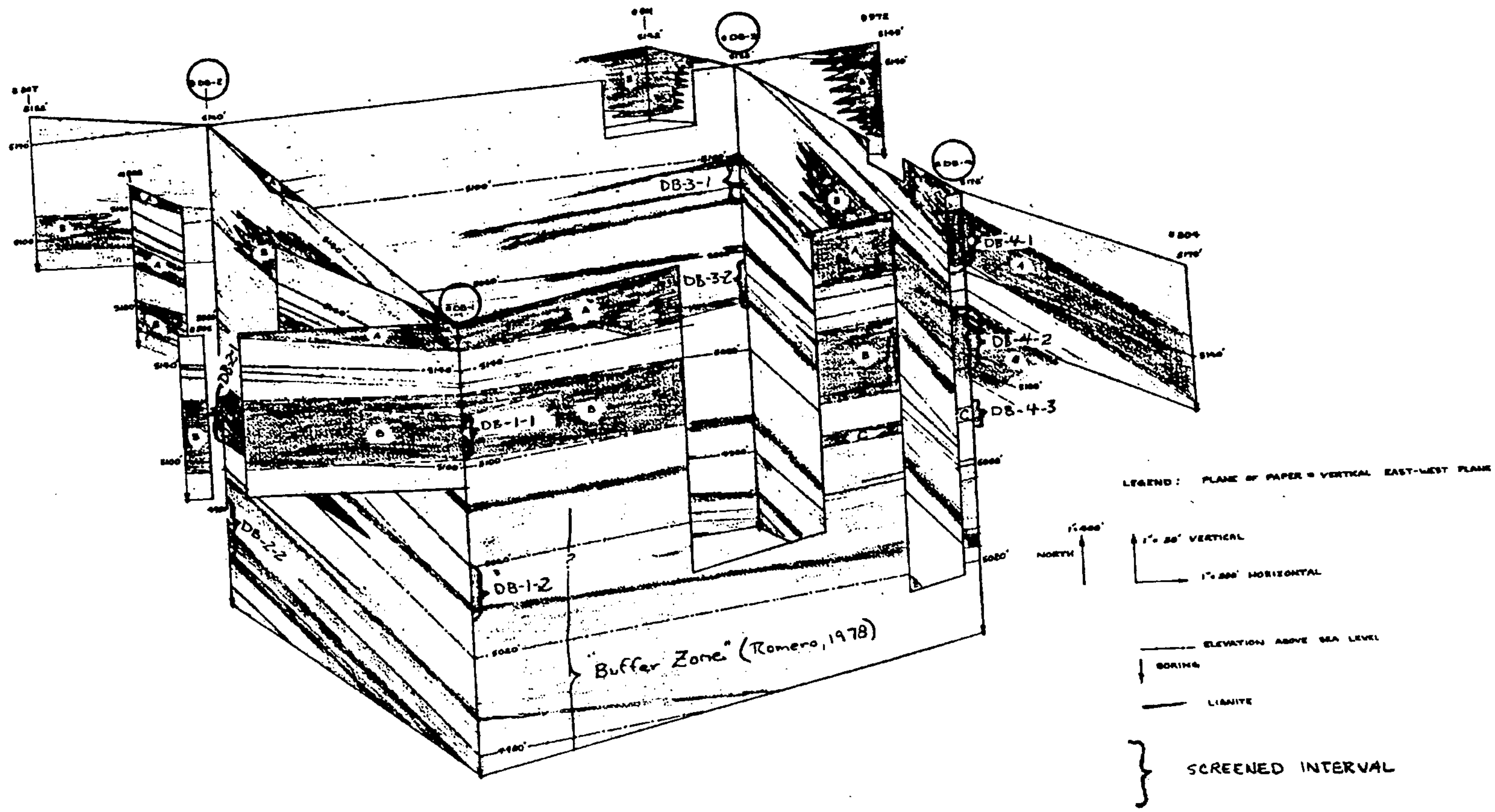

Figure 23. Fence diagram of geologic conditions in the Denver formation in the vicinity of Basin F

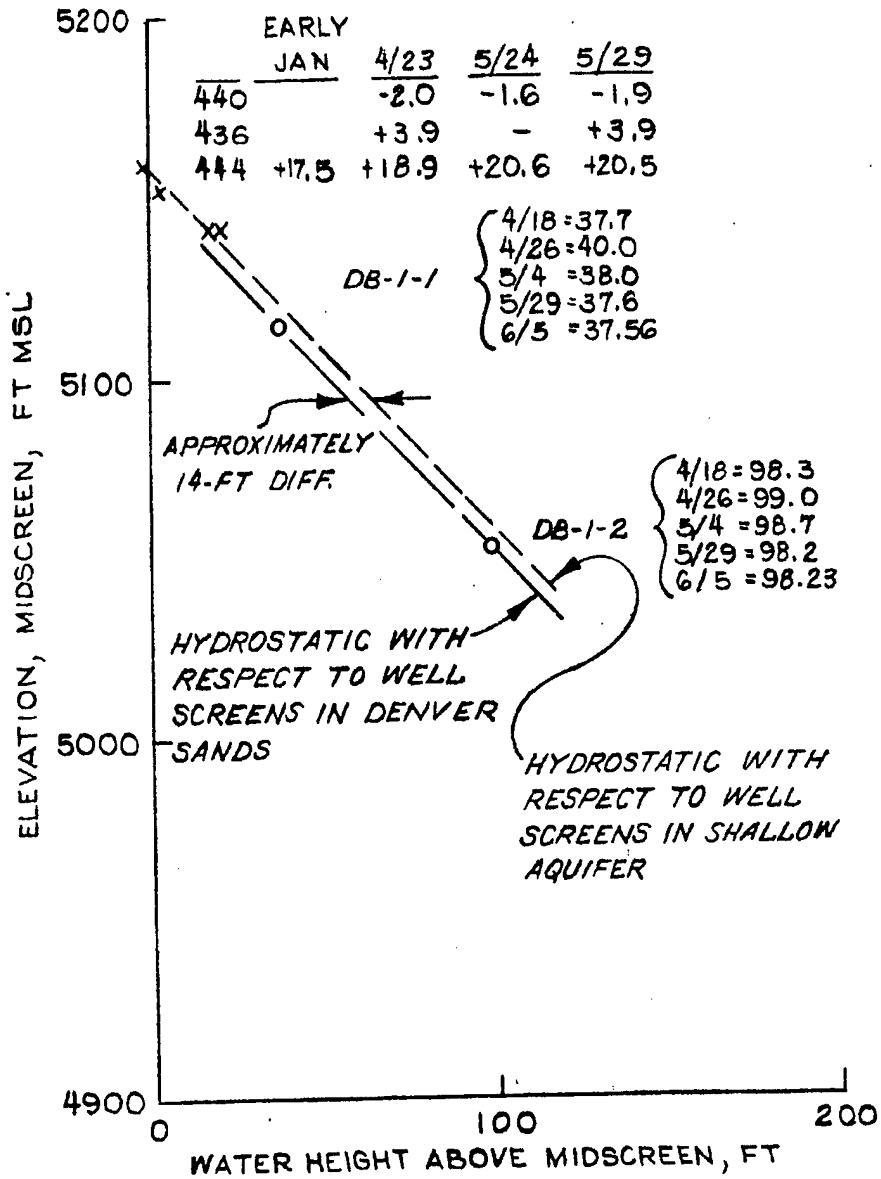

Figure 24. Piezometric levels in vicinity of boring DB-1

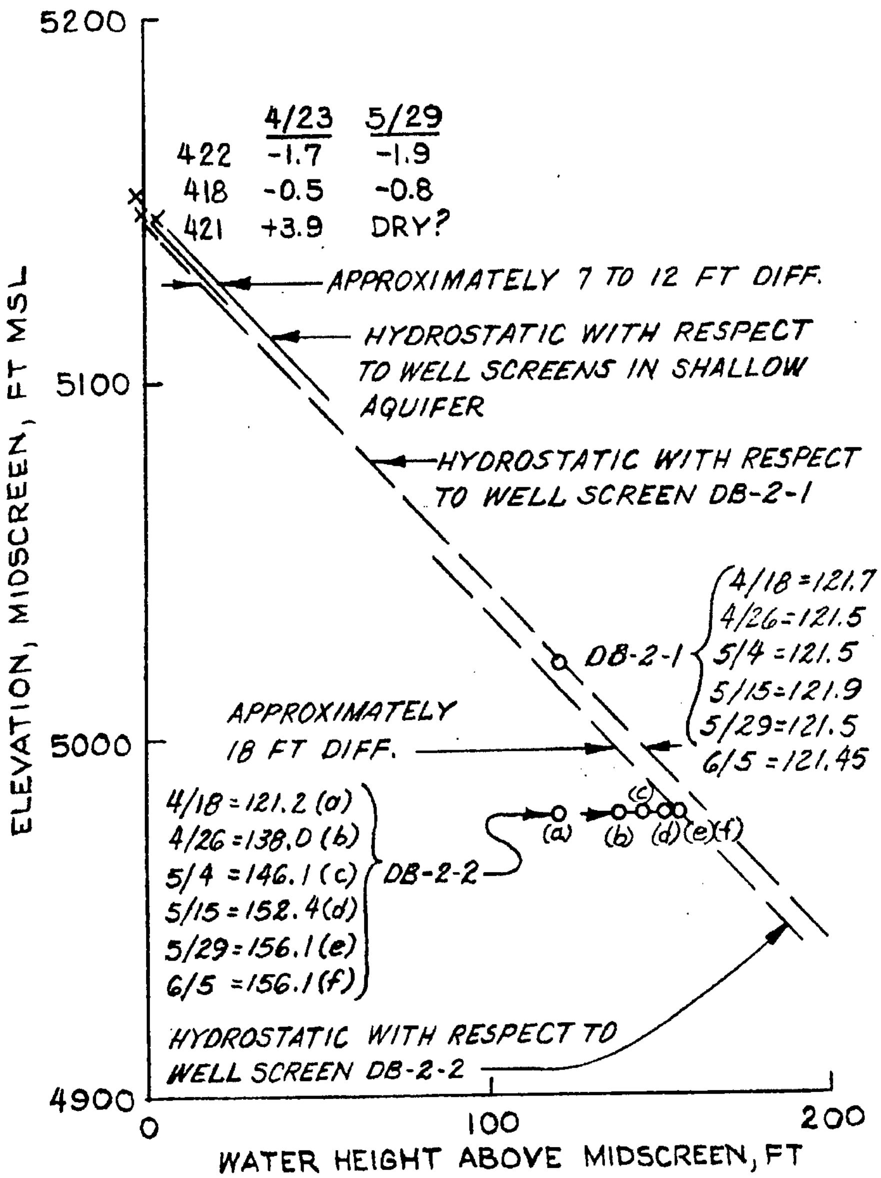

Figure 25. Piezometric levels in vicinity of boring DB-2

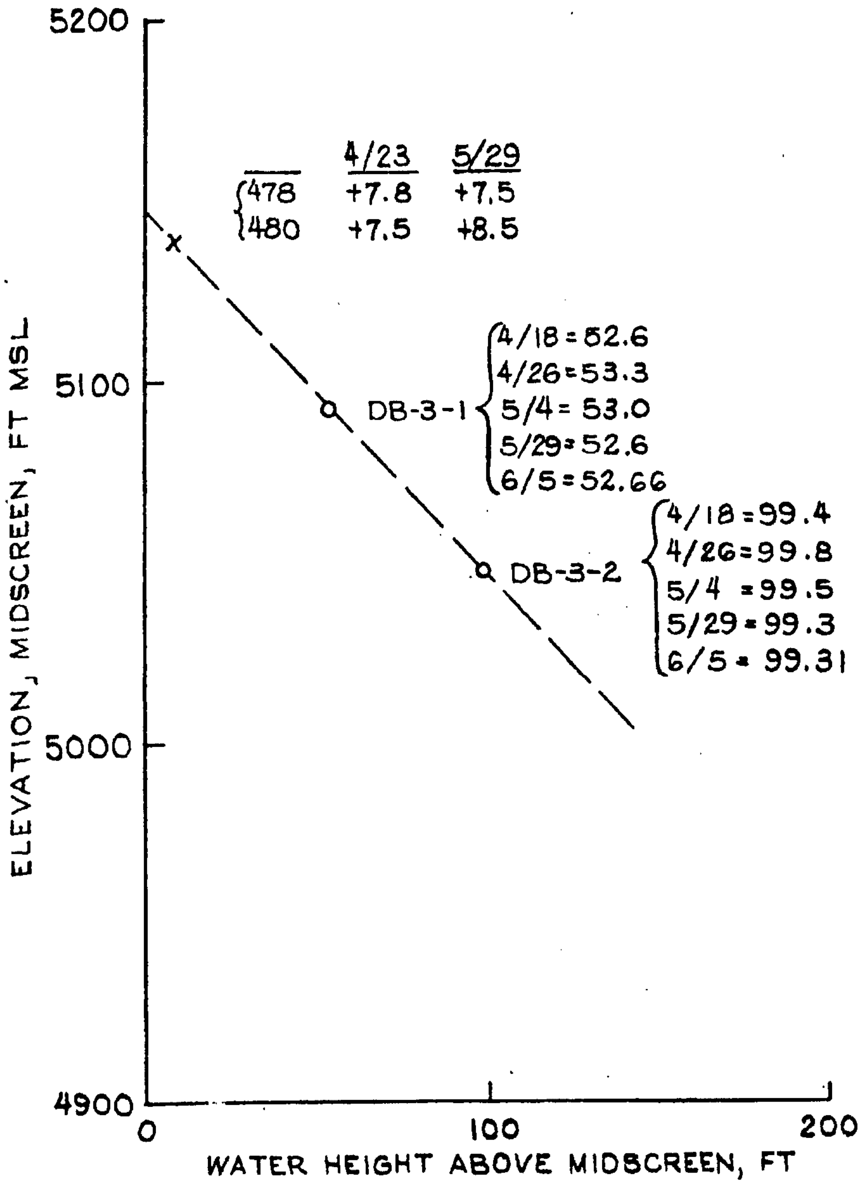

Figure 26. Piezometric levels in vicinity of boring DB-3

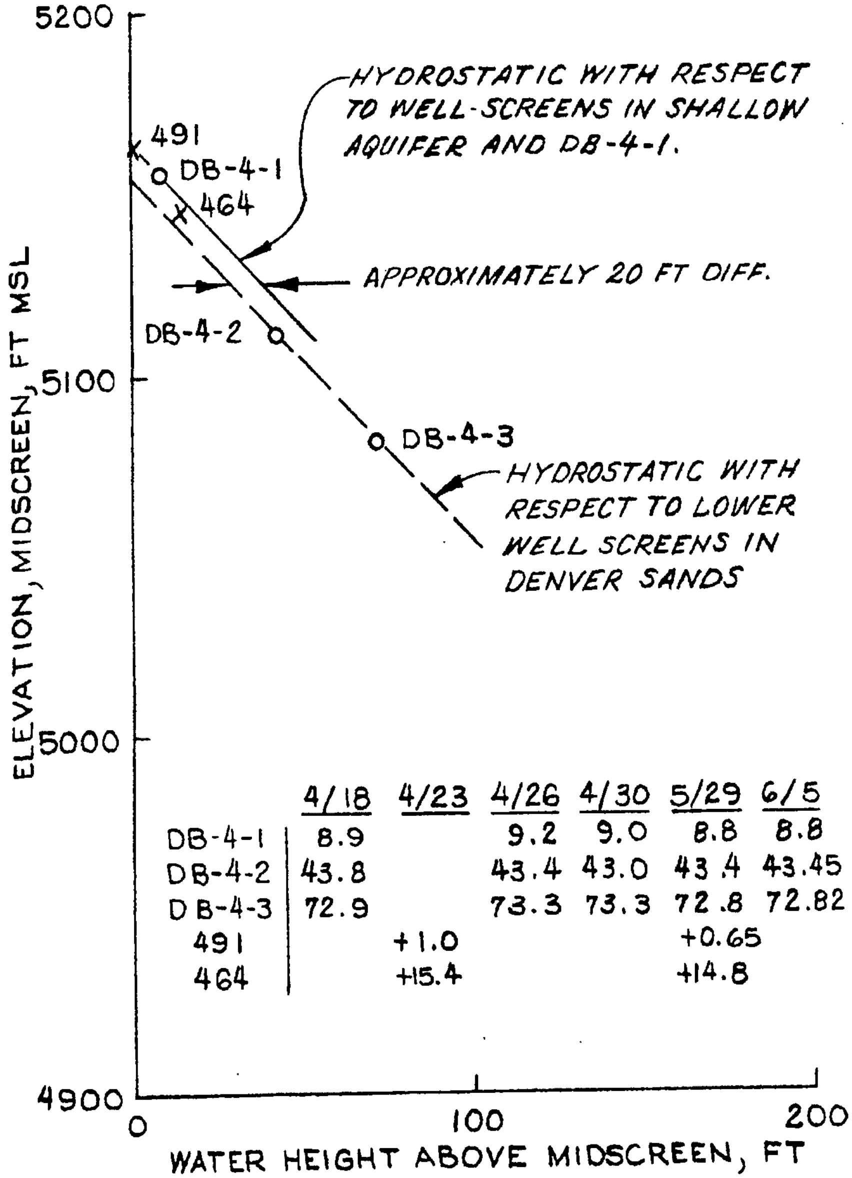

Figure 27. Piezometric levels in vicinity of boring DB-4

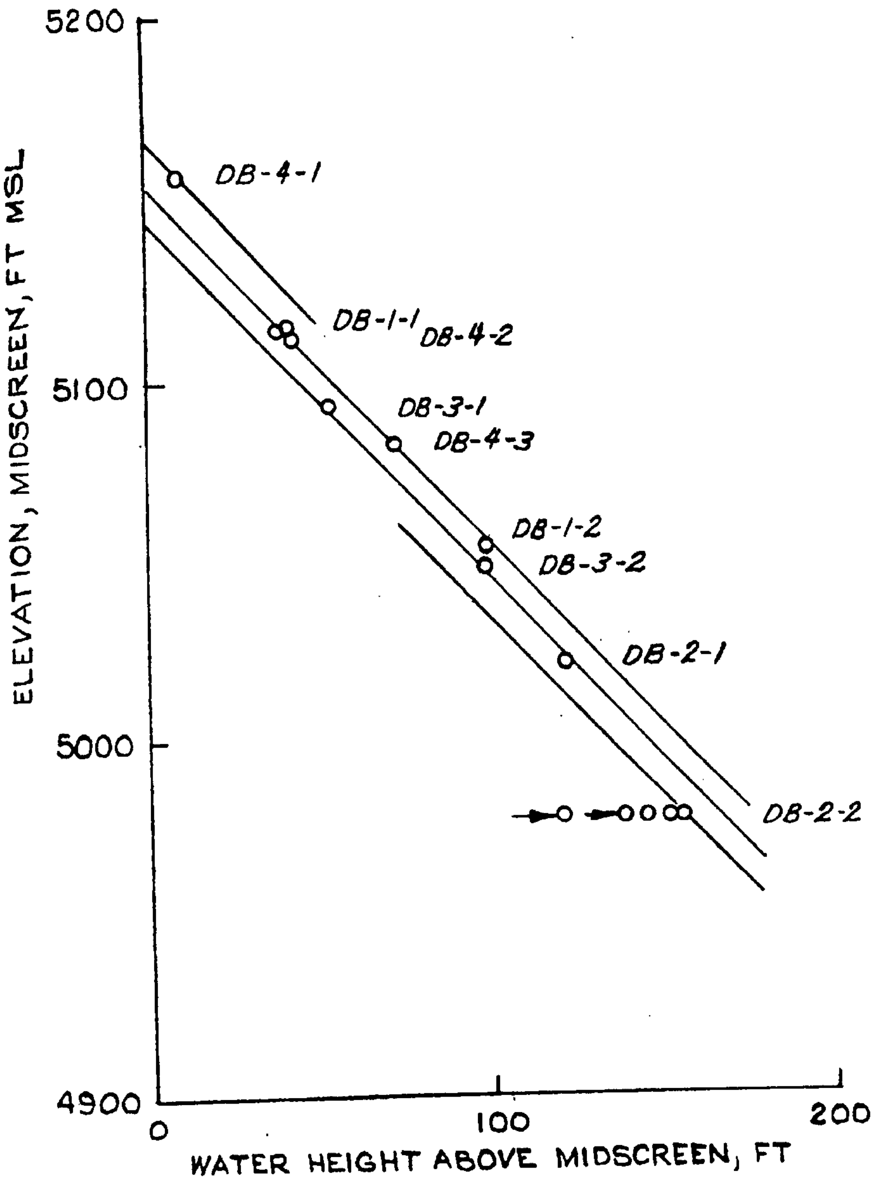

Figure 28. Comparison of piezometric levels in sand lenses in Denver formation

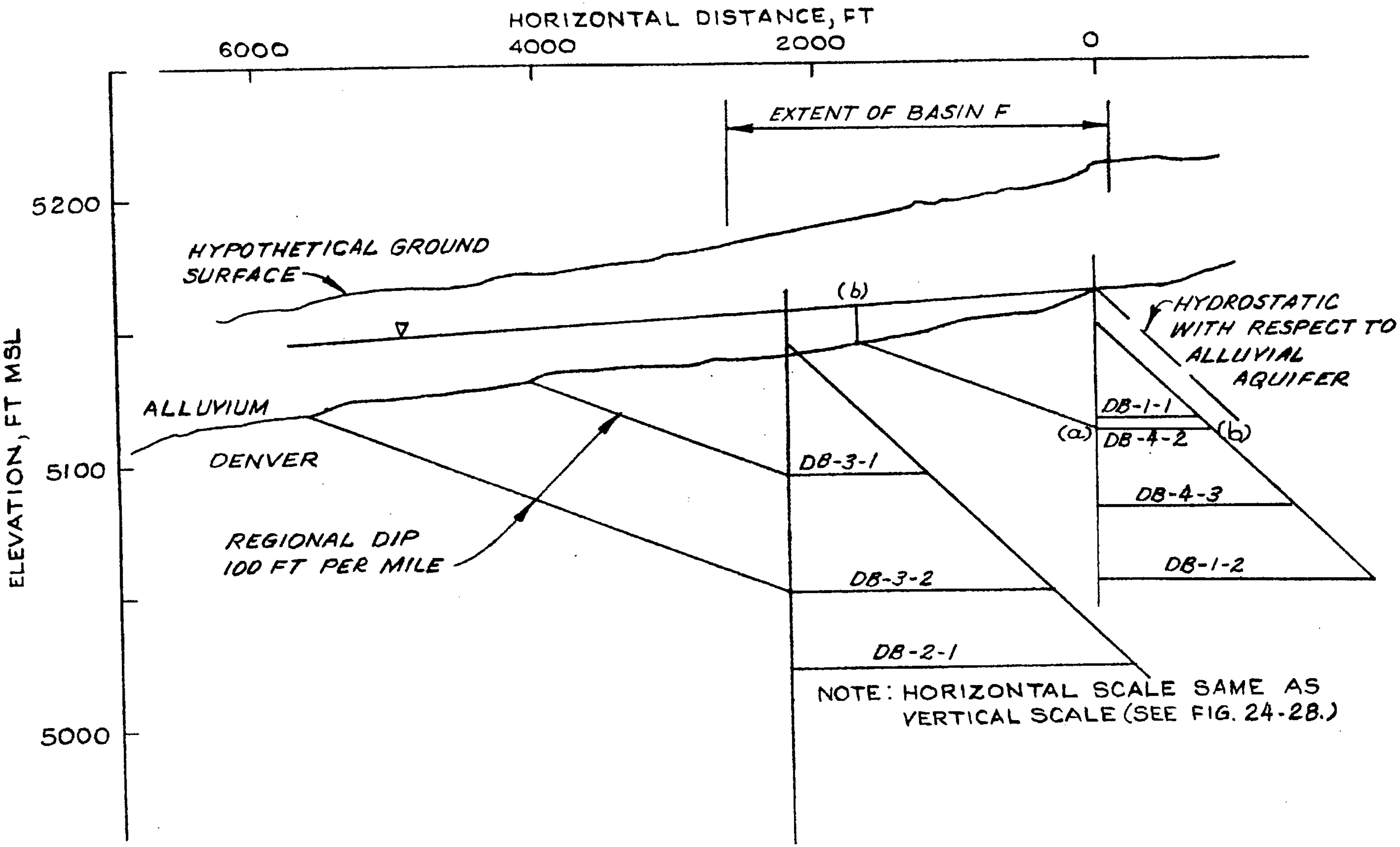

Figure 29. Conceptual subsurface geologic conditions at Basin F

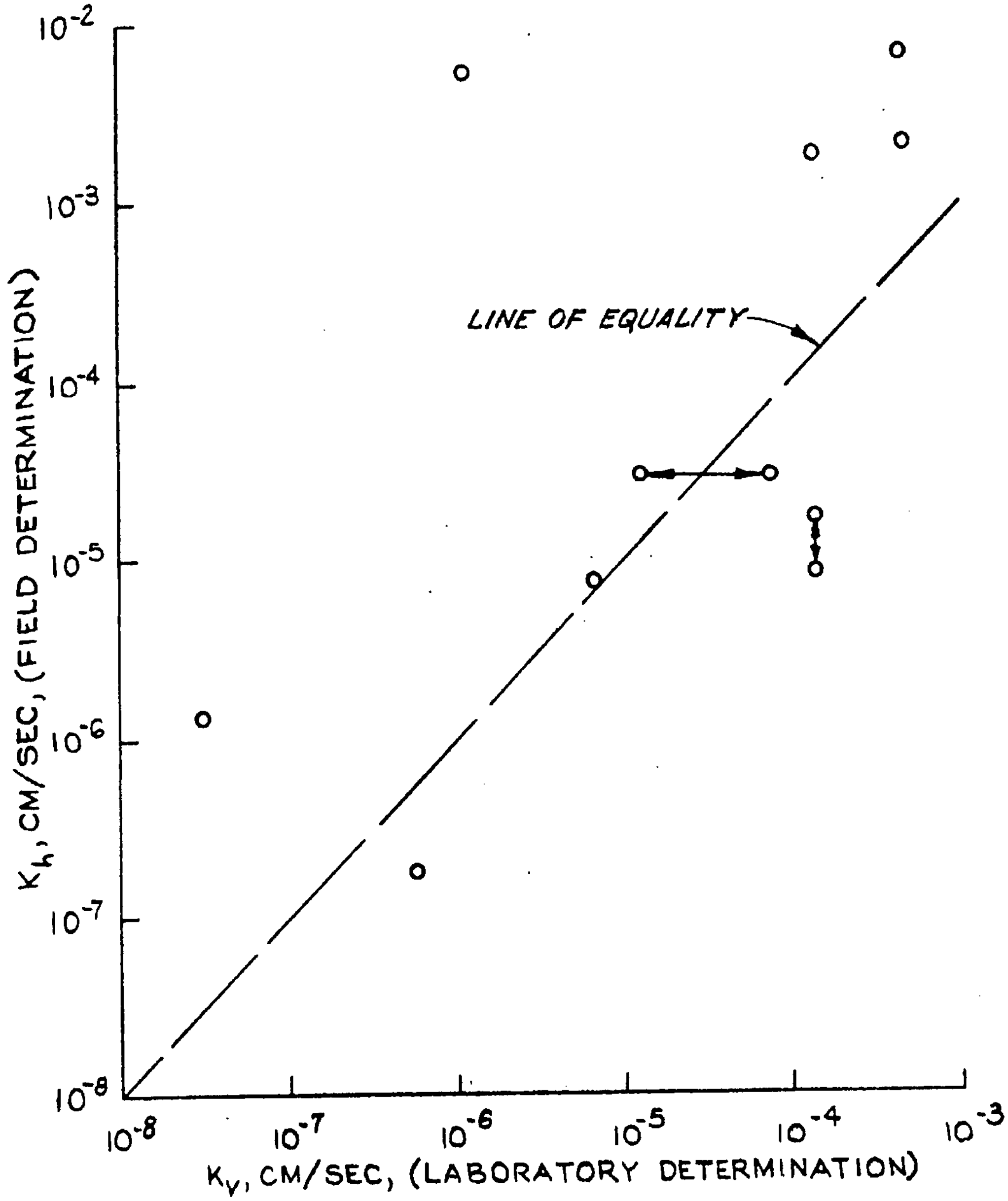

Figure 30. Comparison of coefficients of permeability - laboratory versus field

APPENDIX A: BORING LOGS--FIELD DATA

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal - Deep Borings Site Basin F. R.M.A. Date 2-10-79
Location ______ Job No. ______
Drill Rig CE 9076 Geologist Inspector J. May Operator Clyde Drake Surface El 5197.12 Preliminary bench mark Boring No. DB-1 (493)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
Jar 1	2-10-79	0.0	1.1	0.0	1.1	0.0	0.5	Pitcher sampler		SM	Sand, brown, silty, fn to med. grd.
2		1.1		1.1	3.3	2.4	2.9	"			
3			3.5	3.3	5.9	5.4	5.9	"		ML	Silt, brown, sandy to clayey
4 / 5		3.5	7.3	5.9	8.3	5.9 / 7.9	6.4 / 8.3	"		SM	Sand, yellowish brown, silty, fn. grained
6		7.3	10.9	8.3	10.9	10.4	10.9	"		CL	Clay, tan silty, calc., some sand
7		10.9		10.9	13.4	13.0	13.4	"		CL-CH	
8			15.4	13.4	15.9	15.1	15.6	"		ML	Silt, light tan, fine sand, micaceous, calc.
9		15.4	18.4	15.9	18.4	18.0	18.4	"		CL	Clay, tan, silty, some sand & gravel, calc.
10		18.4		18.4	24.9	19.0	19.4	"		GM	Gravel, multicolored, silty, granitic
11				(Fall in) 20.9	21.7	21.0	21.5	"		"	
12				21.7	24.2	21.9	22.4	"		"	
13	2-12-79		25.6	24.2	25.6	25.0	25.6	"		GM	Gravel, multicolored, silty, cobbles, granitic
14		25.6	32.0	25.6	32.0	25.6	32.0	Rock bit		GC	Gravel and cobbles, clayey in part
15		32.0	32.5	32.0	34.5	34.0	34.5	Pitcher sampler		CL	Clay, gray, silty
16		32.5	41.1	34.5	41.1	34.5	41.1	Rock bit		GC-GW	Gravel and clay, cobbles, granitic
		41.1	49.0	41.1	49.0			"		GC	G[illegible] and clay
		49.0		49.0	52.2			Reamed & cased			Clay shale, olive gray 5Y 4/1 to brn. black (Denver

Sheet 1 of 6 Sheets

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BORING LOG
FIELD DATA

Project Rocky Mtn. - Deep Borings Site Basin F Date 2-12-79
Location Job No.
Drill Rig CE 8076 Inspector J. May Operator Clyde Drake Surface El 5197.12 (Preliminary bench mark) Boring No. DB-1 (493)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
17	2-12-79			52.2	54.4	52.2	52.6	Pitcher			Clay shale, dark gray to olive gray,
18				54.4	56.9	56.4	56.9				carbonaceous, leaf imprints, lignite seams
19	2-12-79			56.9	59.3	58.9	59.3				at 63.9-64.0' and 63.0-63.1'
20	2-13-79			59.3	61.8	61.0	61.8				
21				61.8	64.3	63.9	64.3				
22			66.4	64.3	66.8	66.3	66.8				
~~23~~ 24		66.4	66.8	66.8	69.3	~~67.2~~ 68.9	~~67.7~~ 69.3				Sand, light gray, silty, clay grains
25		66.8	68.4	69.3	71.8	71.4	71.8				Clay, dk gray, silty, carbonaceous
26		68.4	71.8	71.8	74.3	73.9	74.3				Sand, silty gray, fine to med grained, laminated
27		71.8	75.9	74.3	76.8	76.0	76.4				Silt and fn sand, greenish gray, carb, clayey
28		75.9		76.8	79.3	78.9	79.3			SM-SP	Sand, greenish gray, med to coarse
29				79.3	81.8	81.3	81.8				grained, poorly graded, fairly clean,
30				81.8	84.3	83.9	84.3				compact when undisturbed, scattered
31				84.3	86.8	84.3	84.8				pea gravel in top part
32	2-14-79			86.8	89.3	88.8	89.3				
33				89.3	91.8	91.3	91.8				
34				91.8	94.3	93.8	94.3				

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Sheet 2 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal - Deep Borings Site Basin F - R.M.A. Date 2-14-73
Location Job No.
Drill Rig CE 8076 Geol Inspector J. May Operator Clyde Drake Surface El 5197.2 Preliminary bench mark Boring No. DB-1 (493)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
35 / 36	2-14-73		95.2	94.3	96.3	95.0 / [illegible]	95.4 / [illegible]	Pitcher			Sand as above.
37 / 38		95.2		96.3	98.8	97.0 / 98.4	97.4 / 98.8				Clay, dark gray to bluish gray,
39				98.8	101.3	99.0	99.5				silty, carbonaceous, waxey, slickensided
40				101.3	103.8	102.0	102.4				95.8-96.0 lt gray clay - 97.6-98.8 cly siltstone carb.
41			106.3	103.8	106.3	105.0	105.4				Clay as above becoming silty, micaceous
42		106.3		106.3	108.8	106.3	106.6				Silt, greenish gray, compact to
43				108.8	111.3	110.9	111.3				indurated, silty to clayey not
44			113.8	111.3	113.8	113.4	113.8				homogeneous. 111.3-112.0 [illegible]
45 / 46		113.3	114.2	113.8	116.3	113.8 / 116.0	114.3 / [illegible]				Clay, dk gray carb. over gray
											sand 45° sharp contact
		114.2	116.0								Sand, greenish gray compact, silty
											carb. clay balls up to 2"
		116.0	116.3								Clay, dk gray, carbonaceous.
47		116.3		116.3	118.8	118.0	118.4				Clay, dk gr gray, borings, compact brittle,
48				118.8	121.3	120.9	121.3				hard streak at 121.0'-122.0'
49				121.3	123.8	123.3	123.7				darker gray, partially indurated
50				123.8	126.3	126.0	126.3				

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal - Deep Borings Site Basin F - RMA Date 2-15-79
Location ______ Job No. ______
Drill Rig CE 8076 Inspector Jim May Operator Clyde Drake Surface El 5197.12 Preliminary bench mark Boring No. B-1 (493)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
51	2-15-79			126.3	128.5	128.0	129.3	Pitcher			Clay shale, dark gy, blocky, tough, carbonaceous
52				128.8	131.3	131.0	131.3				
53				131.3	133.8	133.3	133.8				
54				133.8	136.3	133.8	134.2				
55				136.3	138.8	138.3	138.8				
56	2-16-79		139.6	138.8	141.3	140.9	141.3				
57		139.6		141.3	143.8	141.3	141.7				Siltstone, gr grey, clayey, micaceous, carbonaceous
58				143.8	146.3	145.9	146.3				laminations 25° from hor., thin
59				146.3	148.8	148.3	148.8				fn sandy streaks, slickensides
60				148.8	151.3	150.8	151.3				
61				151.3	153.8	153.3	153.8				Siltstone, sandy in lower part
62			155.4	153.8	155.8	155.3	156.4				
63		155.4	157.3	155.9	158.3	157.9	158.3				Sandstone, fine, hard gr grey, carb., silty
64		157.3		158.3	160.8	160.3	160.8				Claystone (shale), grn. grey, blocky, tough,
65				160.8	163.3	162.9	163.3				silty to fn sd lamina
66				163.3	165.8	165.3	165.8				"
67				165.8	168.3	167.8	168.3				

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal - Deep Borings Site Basin F Date 2-17-79
Location Job No.
Drill Rig CE 9576 Inspector Jim May Operator Clyde Duke Surface El 5197.12 Preliminary bench mark Boring No. DB4 (1493)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
68	2-17-79			168.3	170.8	170.3	170.8	Pitcher			Claystone-shale, dk gr gray
69				172.8	173.3	172.8	173.3				silty, carbonaceous, tough
70	2-17-79			173.3	175.8	175.3	175.8				Clay shale, dk to gr gray, silty,
71			175.8	175.8	178.3	177.8	178.3				some carbonaceous in lower part.
72		175.8		178.3	181.8	181.3	181.8				Clayshale, gr, gray, friable, less carb,
73				181.8	184.3	183.3	184.3				montmorillonitic
74				184.3	185.8	185.3	185.8				Clayshale darker gr gy, tougher
75	-			185.8	188.3	187.8	188.3				than above
76	2-19-79			188.3	190.3	189.9	190.3				
77				190.3	192.8	192.3	192.8				
78			195.3	192.8	195.3	194.8	195.3				
79		195.3		195.3	197.8	197.3	197.8				Clay shale, gr, gray, silty, carb,
80			199.0	197.8	200.3	199.8	200.3				indurated in part
81		199.0	200.3	200.3	202.8	202.3	202.3				Siltstone, lt gr gray, sandy, micaceous
82		200.3	201.1	202.8	205.3	204.8	205.3				Sand, fn, gr gray, silty
83	2-20-79	201.1	208.6	205.3	207.8	207.3	207.8				Clayshale, gr gy to gy bk, tough
84		208.6		207.8	210.3	209.8	210.3				Siltstone, green gray, clayey, tough

Sheet 5 of 6 Sheets

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal - Deep Borings Site Basin F Date 2-20-79
Location Job No.
Drill Rig CE 8076 Inspector Jim May Operator Clyde Drake Surface El 5197.12 Preliminary bench Boring No. DB-493

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
85	2-20-79			212.3	212.8	212.3	212.8	Pitcher			Siltstone, grn gray to dark gray
86				212.8	215.3	214.5	215.3				micaceous, carbonaceous, sandy
87			217.0	215.3	217.8	215.3	215.8				to clayey, inhomogeneous
88		217.0		217.8	220.3	219.8	220.3				Clay shale, grn gray, silty,
89				220.0	222.8	222.3	222.8				carbonaceous, indurated in part
90				222.8	225.3	224.8	225.3				Clay shale, grn gry, silty,
											micaceous, tough, indurated
											in part

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

Sheet 6 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal Site Basin F Date 2-20-79
Location Job No.
Drill Rig CE 4524 Inspector Jim May Operator Gene Wehrhorst Surface El 5185.57 preliminary bench mark Boring No. DB-2 (494)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
	2-20-79	0.0		0.0	2.5	no	sample	Pitcher		ML	Silt, rd brown, sandy, iron stain
1				2.5	5.0	4.5	5.0			ML	"
2			7.5	5.0	7.5	7.0	7.5			ML	"
3		7.5	10.0	7.5	10.0	9.5	10.0			MH	Silt, lt tan, clayey, calcareous
4	2-20-79	10.0	12.5	10.0	12.5	12.0	12.5			SM	Sand, rd brown, silty to gravelly
5	2-21-79	12.5		20.0	30.0	20.0	30.0	Rock bit (Cuttings)		GM-GC	Gravel, clayey to silty, iron stain
6				30.0	40.0	30.0	40.0			GM-GW	"
7			45.0	40.0	45.0	40.0	45.0			"	
8	2-22-79	45.0		45.5	48.5	48.0	48.5				Clay shale, lt to dk. gray, tough (Denver)
9				48.5	50.0	49.5	50.0				to friable, laminated, carb. leaf
10				50.0	52.5	51.8	52.5				imprints, amber, swells (expansive)
11				52.5	55.0	54.5	55.0				slickensided, indurated in part
12				55.0	57.5	57.0	57.5				
13				57.5	60.0	59.5	60.0				
14	2-23-79			60.0	62.5	62.0	62.5				
15			65.5	62.5	65.5	65.0	65.5				
16		65.5		65.5	67.5	67.0	67.5				Clay shale, grn gray, tough to laminated

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

Sheet 1 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal Site ______ Date 2-20-79
Location ______ Job No. ______
Drill Rig CE 4524 Geologist Inspector Jim May Operator Gene Warhorst Surface El 5185.57 preliminary bench mark Boring No. 494

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
17	2-23-79			67.5	70.0	69.5	70.0	Pitcher			Clay shale, grn grey to dk gray, tough
18				70.0	72.5	72.0	72.5				to fissile, carbonaceous, indurated
19			73.0	72.5	75.0	74.5	75.0				in part
20		73.0		75.0	77.5	77.0	77.5				Siltstone, grn gray, laminated, sandy streaks
21			80.0	77.5	80.0	79.6	80.0				large mica flakes, leaf imprints
22		80.0		80.0	82.5	82.0	82.5				Clay shale, greenish grey to dark
23				82.5	85.0	84.5	85.0				gray, massive to laminated, brown
24				85.0	87.5	87.0	87.5				nodule at 85.6', friable, indurated
25				87.5	90.0	89.5	90.0				in part, montmorillonitic
26				90.0	92.5	92.0	92.5				
27				92.5	95.0	94.5	95.0				
28				95.0	97.5	97.0	97.5				
29				97.5	100.0	99.5	100.0				
30				100.0	102.5	102.0	102.5				
31	2-24-79			102.5	104.6	104.1	104.6				Silty streak 102.0-103.0'
32				104.6	107.2	106.8	107.2				50° fault plane at 102.0'
33			103.5	107.2	109.8	109.3	109.8				

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

Sheet 2 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal Site Basin F Date 2-26-78
Location ______ Job No. ______
Drill Rig CE 4524 Geologist Inspector Jim May Operator Gene Weihorst Surface El 5185.57 preliminary bench mark Boring No. 494

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
34		108.5	110.3	109.8	112.5	112.0	112.5	Pitcher			Siltstone, grn gray, clayey, carb. lam.
35		110.3	114.6	112.5	115.0	114.6	115.0				Clay shale, dk gray tough carb.
36		114.6		115.0	117.1	116.7	117.1				Siltstone, grn gray, laminated, silty
37				117.1	119.5	119.0	119.5				
38				119.5	122.2	120.5	121.0				
39			121.0			121.8	122.2				
40		121.0		122.2	124.6	124.1	124.6				Clay shale, grn gray, silty, carb.
41				124.6	127.3	126.8	127.3				Tough, laminated in part,
42			129.6	127.3	129.6	129.1	129.6				indurated in part
43	2-26-79	129.6		129.6	132.2	131.8	132.2				Siltstone, dk gray, clayey, fn sand
44			133.0	132.2	134.7	134.3	134.7				streaks, carbonaceous,
45		133.0		134.7	137.3	136.8	137.3				Clayshale, dk gray, silty, carb.
46				137.3	139.7	139.3	139.7				laminated,
47				139.7	142.3	141.8	142.3				
48				142.3	144.7	144.3	144.7				blocky bentonitic, less carb.
49				144.7	147.3	146.8	147.3				partially indurated
50				147.3	148.0	147.6	148.0				

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal Site Basin F Date

Location Job No.

Drill Rig CE 4524 Inspector Jim May Operator Gene Warhurst Surface El 5185.57 preliminary bench mark Boring No. 484

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
51	2-26-79			143.0	150.0	149.6	150.0	Pitcher			Clay shale (as above)
52			151.5	150.0	152.5	152.1	152.5				
53		151.5		152.5	154.7	154.2	154.7				Sandstone, grn gray, med to coarse
54				154.7	157.5	157.0	157.5				grained, silty, very hard in part,
55				157.5	159.2	158.9	159.2				damp (not a lot of water)
56	2-28-79			159.2	161.0	160.6	161.0				calcareous cement around 160
57				161.0	161.5	161.0	161.5				
				161.1	167.5			Rock bit			no sample but hard s.s.
				167.5	170.5						
58				170.5	173.0	172.6	173.0	Pitcher			
59				173.0	175.5	175.0	175.5				
60			176.5	175.5	177.6	176.0	176.5				
61		176.5				177.1	177.6				Clay shale, greenish gray to dark
62				177.6	180.1	179.6	180.1				gray, slickensides, carbonaceous,
63				180.1	182.6	182.1	182.6				.5 inch lignite at 187.9', thin
64				182.6	185.1	184.6	185.1				hard streaks
				185.1	187.5						

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

Sheet 4 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal Site Basin F Date 3-3-79
Location Job No.
Drill Rig CE 4524 Inspector Jim May Operator Gene Wakhurst Surface El 5185.57 preliminary bench mark Boring No. 494

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
65	3-1-79			187.5	188.9	188.3	188.9	Pitcher			Clay shale, greenish gray to
66				188.9		189.0	189.4				dark gray, silty, laminated
67						190.0	190.4				carbonaceous, slickensides
68			191.0		191.4	191.0	191.4				
69		191.0	192.0	191.4	194.1	193.7	194.1				Sandstone, gray, hard, fn to med gr.
70		192.0		194.1	196.1	196.2	196.1	|			Clay shale, dark gray, silty
71			199.4	196.7	199.4	199.0	199.4				to sandy, tough, indurated in part
72	3-2-79	199.4		199.4	201.9	201.4	201.9				Siltstone, greenish gray,
73			202.9	201.9	202.9	202.4	202.9				white specks, carb., very hard,
74		202.9		202.9	205.4	205.0	205.4				Clay shale, grn gray, core
75				205.4	207.9	207.4	207.9				sandstone at 203.3 - 203.8',
76			209.6	207.9	210.4	210.0	210.4				indurated in part
77		209.6	212.1	210.4	212.1	210.7	211.1				siltstone, grn gray, carbonaceous
78		212.1		212.1	212.7	212.2	212.7				thin micaceous sand streaks 212.1'
								Rock bitted			Sandstone, lt. grn gray, very
			216.6								hard.
79	3-3-79	216.6	219.0	216.6	219.0	218.5	219.0	Pitcher			Clay shale, grn blk, silty to sandy

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal Site Basin F Date 3-6-79
Location Job No.
Drill Rig CE 4524 Geologist Inspector Jim May Operator Gene Warhurst Surface El Boring No. 4494

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
80	3-3-79	219.0	221.0	219.0	221.5	221.0	221.5	Pitcher			Siltstone, lt grn gray, carb., sandy
81		221.0	222.6	221.5	223.5	222.3	222.8				Clay shale, dk gray to olive bk, tough, blocky 60° slick.
82		222.6		223.5	224.2	223.6	224.2				Sandstone, lt grn gray, very hard, med.
			226.2	224.2	226.2			Rock bit			to coarse grd; conglomeratic
83		226.2		226.2	228.7	228.2	228.7	Pitcher			Clay (shale) grn gray, blocky, mod.
84				228.7	230.7						silty, carb. in upper part,
85	3-5-79			230.7	232.7	232.2	232.7				229.4-229.8 calc. hard zone
86				232.7	235.8	235.3	235.8				
87				235.8	238.1	237.6	238.1				hard brown nodules (siderite?)
88	3-6-79			238.1	239.9	239.4	239.5				
89				239.9	242.2	241.7	242.2				darker gn gray, carb. slickensides
90				242.2	243.7	243.2	243.7				
91				243.7	245.2	244.7	245.2				

WES FORM 819 JAN 74 EDITION OF NOV 1971 MAY BE USED

Sheet 6 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal Site Basin F Date 3-3-79
Location Job No.
Drill Rig CE 9076 Geologist Inspector Jim May Operator Clyde Drake Surface El Boring No. (495) DB3

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
1	3-2-79	0.0		0.0	2.5	2.0	2.5	Pitcher		SM	Sand, rd br, silty, iron stained
2			5.0	2.5	5.0	4.5	5.0			SM	Sand brown, silty, iron stained
3		5.0		5.0	7.5	7.0	7.5			ML	Silt, brown, clayey, calcareous
4				7.5	10.0	9.5	10.0			"	Silt. " " "
5				10.0	12.5	12.0	12.5			"	" very calcareous
6			15.0	12.5	15.0	14.5	15.0			ML	Silt, brown, clayey, scattered gravel
7		15.0	16.5	15.0	17.5	17.0	17.5			SM	Sand, rd br. clayey
8		16.5		17.5	20.0	19.5	20.0			GM	Gravel, silty to clayey, (clay streaks)
			50.6	20.0	50.6	none		Rock bit		GM-GC	" " cobbles cemented in part
9		50.6		54.5	57.0	56.5	57.0	Pitcher			Clay shale, lt gray to dark (Denver)
10				57.0	59.5	59.0	59.5				gray, silty, montmorillonitic,
11				59.5	62.0	61.5	62.0				indurated in part
12				62.0	64.5	64.0	64.5				"
13				64.5	66.2	65.7	66.2				"
14				66.2	68.9	68.3	68.8				" hard str at 67.6
15				68.8	71.3	70.9	71.3				"
16				71.3	73.3	72.3	72.8				" dark gray, lignitic 50° joint

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

Sheet 1 of 6 Sheets

BORING LOG
FIELD DATA

Project: Rocky Mtn Arsenal (Deep borings) Site: Basin F Date:
Location: Job No.:
Drill Rig: CE 307C Geologist Inspector: Jim May Operator: Clyde Drake Surface El: 5198.61 Boring No.: 495 (DB-3)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
17	3-6-79			73.8	76.8	76.3	76.8	Pitcher			Clay shale, dk gray, silty, carbonaceous,
18				76.8	79.3	78.8	79.3				slickensided joints, bentonitic
19				79.3	81.8	81.3	81.8				"
20				81.8	84.3	83.8	84.3				" very silty, laminated
21				84.3	86.8	86.3	96.8				" sandfilled 70° joint at 86.0'
22			87.7	86.8	89.3	88.8	89.3				-
23		87.7	91.8	89.3	91.8	91.3	91.8				Sandstone, lt grn gray, med. grd. silty
24		91.8		91.8	94.3	93.8	94.3				Clay shale, dk gray to grn gray,
25				94.3	96.8	96.3	96.8				carbonaceous, laminated, silty, very
26			98.0	96.8	99.3	98.2	99.3				hard, in part 75° clay-to-sand contact
27	3-7-79	98.0	101.0	99.3	101.8	101.3	101.8				Sandstone, brn gray, silty, mdi
28		101.0	103.3	101.8	103.3	102.8	103.3				Clay shale, brn, carb. silty
29		103.3		103.3	103.8	103.3	103.8	Dia. Core			Sandstone, light gray, very hard,
30			105.9	103.8	106.8	105.6	106.0	Pitcher			conglomeritic, silty, 105.6 - .3' lignite
31		105.9		109.7	110.7	110.2	110.7				Clay shale, dk bl gray, bentonitic
32				110.7	113.2	110.7	111.3				110.7'-112.5' vertical contact, clay and
33				113.2	115.8	115.3	115.8				choc. brown sand

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project: Rocky Mtn. Arsenal Site: Basin F Date:
Location: Job No.:
Drill Rig: CE 8076 Geologist Inspector: Jim May Operator: Clyde Drake Surface El: 5188.61 Boring No.: 495 (DB-3)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
34	3-7-79			115.8	118.3	113.8	118.3	Pitcher			Clayshale, dark to grn gray,
35				118.3	120.8	120.3	120.8				silty to sandy, montmorillonitic,
36				120.8	123.3	122.8	123.3				indurated in part
37			124.5	123.3	125.8	125.3	125.8				
38		124.5	128.0	125.8	128.3	127.8	128.3				Sandstone, gray, fine grd, carb.
39		128.0		128.3	130.8	130.3	130.8				Clayshale, grn gray to dark
40				130.8	133.3	132.8	133.3				gray, carb., blocky to laminated,
41				133.3	135.8	135.3	135.8				montmorillonitic
42	3-9-79		137.5	135.8	138.3	137.8	138.3				
43		137.5	140.8	138.3	140.8	140.3	140.8				Siltstone, med. gray, carb., compact
44		140.8		140.8	143.3	142.8	143.3				Clayshale, dark gray, carbonaceous,
45				143.3	145.8	145.3	145.8				silty to sandy.
46			146.0	145.8	148.3	147.2	148.3				
47		146.0	149.0	148.3	150.8	150.3	150.8				Sand, gray, fn to md grd, compact, damp
48		149.0		150.8	153.3	152.8	153.3				Clayshale, dk to grn gray, carb.
49				153.3	155.8	155.3	155.8				many plant imprints, bentonitic, brown
50				155.8	158.3	157.8	158.3				concretions (siderite?)

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

BORING LOG
FIELD DATA

Project Rocky Mtn Arsenal Site Basin F Date

Location Job No.

Drill Rig CE 8076 ~~Inspector~~ Geologist Jim May Operator Clyde Drake Surface El 5188.61 Boring No. ~~495~~ (DB-3)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
51	3-9-79			158.3	160.8	160.3	160.8	Pitcher			Clay shale, dk gray to grn gray,
52	3-10-79			160.8	163.3	162.8	163.3				less carb. material, more montmorillonitic
53				163.3	165.8	165.3	165.8				tough blocky, bentonitic appearing.
54				165.8	166.8	166.3	166.8				"
55				166.8	169.3	168.8	169.3				"
56				169.3	171.8	171.3	171.8				"
57				171.8	174.3	173.8	174.3				" very little carb. material
58				174.3	176.8	176.3	176.8				
59				176.8	179.3	178.3	179.3				" indurated streaks
60				179.3	181.8	181.3	181.8				"
61				181.8	184.3	183.8	184.3				" hard streaks, bentonitic
62				184.3	186.8	186.3	186.8				"
63	3-12-79			186.8	189.5	189.0	189.5				
64				189.5	192.2	191.7	192.2				Clay shale, dk gray, silty, tough
65				192.2	194.7	194.2	194.7				carbonaceous, slickensides
66			195.4	194.7	197.2	196.7	199.2				
67		195.4		197.2	199.2	198.7	199.2				Sandstone, gn gray, very hard, conglomeritic

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

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BORING LOG
FIELD DATA

Project: Rocky Mtn Arsenal Site: Basin F Date:
Location: Job No.:
Drill Rig: CE 8076 Geologist / Inspector: Jim May Operator: Clyde Drake Surface El: 5188.61 Boring No.: 495 (DB-3)

SAMPLE NUMBER	DATE TAKEN	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
68	3-12-75		200.5	199.2	202.1	201.9	202.1	Pitcher			Sandstone, grn gray, congl. very hard, clay
69		200.5		202.1	203.2	203.0	203.2				Clay shale, dk to grn gray
70				203.2	205.7	205.2	205.7				tough, blocky, silty, slickensides,
71				205.7	208.2	207.7	208.2				brown concretions in lower part (siderite?)
72			210.7	208.2	210.7	210.2	210.7				
73		210.7	213.2	210.7	213.2	212.7	213.2				Siltstone, grn gray, micaceous, shaley at 212.6
74		213.2	213.5	213.2	215.7	213.2	213.7				Sand, grn grey, micaceous, damp.
75		213.5		215.7	218.2	217.7	218.2				Clay shale, grn gray, montmorillonitic,
76				218.2	220.7	220.2	220.7				tough; slickensided, blocky,
77				220.7	223.2	222.7	223.2				
78	3-14-75			223.2	225.7	225.2	225.7				
79			227.0	225.7	227.7	227.2	227.7				
80		227.0	230.0	227.7	230.2	229.7	230.2				Sandstone, lt grn gray, very hard
81		230.0		230.2	232.7	232.2	232.7				Clay shale, med to dk gray, silty
82			234.3	232.7	235.2	234.3	234.8				to sandy, carbonaceous, waxey in bot. part
83		234.3		235.2	237.7	237.2	237.7				Siltstone, lt to dk gray, sandy
84				237.7		237.7	239.2				very hard in part, carbonaceous

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

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BORING LOG
FIELD DATA

Project: Rocky Mtn. Arsenal (Deep Borings) Site: Basin F Date: ______
Location: ______ Job No. ______
Drill Rig: CE 8076 Geologist Inspector: Jim May Operator: Clyde Drake Surface El: 5188.61 Boring No. 485 (DB-3)

SAMPLE NUMBER	DATE TAKEN	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
85	3-14-79		239.0		240.2	239.7	240.2	Pitcher			Siltstone, lt to dk gray, sandy to
86				240.2	242.6	242.1	242.6				clayey, very calc. damp.
		239.0	242.6								Clay shale, grn gray, montmorillonite
											tough, blocky.

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Sheet 6 of 6 Sheets

BORING LOG
FIELD DATA

Project Rocky Mtn. Arsenal Site Basin F Date 3-22-79
Location Job No.
Drill Rig CE 4524 Inspector Geologist J.H. May Operator Gene Whitehurst Surface El Boring No. DB-4 (4&L)

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
	3-22-79	0.0		0.0	2.5	No	Sample	Pitcher		SM	Sand, rd brown, silty, coarse to
1				2.5	5.0	4.5	5.0	"		"	med. grained, calcareous, oxidized
2				5.0	7.5	7.0	7.5	"		"	
3				7.5	10.0	9.5	10.0	"		"	
4			12.5	10.0	12.5	12.0	12.5	"		"	
5		12.5		12.5	15.0	14.5	15.0	"		SM	Sand, rd brown, fine to med. grd.
6				15.0	17.5	17.0	17.6	"			calcareous
7			20.0	17.5	20.0	19.5	20.0	"			
8		20.0		20.0	22.5	22.0	22.5	"		MH	Silt, rd brown, clayey, calcareous
9			24.5	22.5	25.0	24.5	25.0	"		"	
10		24.5	27.5	25.0	27.5	27.0	27.5	"		CL-CH	Clay, lt. tan, silty, very calc. (some gravel)
11				27.5	30.0	29.5	30.0	"		MH	Silt, lt. brown, clayey, calc, gravelly
12				30.0	32.5	32.0	32.5	"		MH	"
13			35.0	32.5	35.0	34.5	35.0	"		MH	"
14		35.0	37.5	35.0	37.5	37.0	37.5	"		SM	Sand, lt. brown, silty, gravelly
-		37.5	48.0	37.5	48.0	No	Sample	Rock bit		GM-GC-CH	Gravel, sand and clay, lenses
-		49.0	55.5	48.0	55.0	No	Sample	Rock bit		CH	Clayshale, brown, silty, tough (Denver)

WES FORM JAN 74 819 EDITION OF NOV 1971 MAY BE USED

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BORING LOG
FIELD DATA

Project: Rocky Mtn Arsenal Site: Basin F Date: 3-23-79
Location: Job No.:
Drill Rig: CE 45524 Inspector: J. May Operator: Gene Wachurst Surface El.: Boring No.:

SAMPLE NUMBER	DATE TAKEN	STRATUM FROM	STRATUM TO	DRIVE FROM	DRIVE TO	SAMPLE FROM	SAMPLE TO	TYPE OF SAMPLER			CLASSIFICATION AND REMARKS
15	3-23-79	55.5		55.0	57.0	55.0	55.5	Pitcher		SMSP	Sand, reddish brown, medium to
16				57.0	59.5	59.0	59.5				coarse grained, micaceous,
17				59.5	62.0	61.0	61.5				dark minerals, reddish materials,
18				62.0	64.5	64.0	64.5				oxidized (Denver) clay balls
19				64.5	67.0	66.5	67.0				and rounded sandstone pebbles,
20				67.0	69.5	69.0	69.5				
21				69.5	72.0	71.5	72.0				
22				72.0	74.5	74.0	74.5				
23			77.5	74.5	77.0	76.5	77.0				
24		77.3		77.0	79.5	77.2	77.7				Clay shale, black, carbonaceous
25				79.5	82.0	81.5	82.0				silty, blocky to laminated
26			82.9	82.0	84.3	82.0	82.5				
27		82.9	84.9	84.3	86.9	86.3	86.9				Siltstone, light to dark gray, sandy
28		84.9		86.9	89.5	89.0	89.5				Clay shale, dark gray to black,
29				89.5	92.0	91.5	92.0				very carbonaceous, slickensides
30				92.0	94.5	94.0	94.5				
31			95.6	94.5	95.9	95.3	95.9				

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BORING LOG
FIELD DATA

Project: Rocky Mtn Arsenal   Site: [illegible] F   Date: [illegible]
Location: Job No.:
Drill Rig: CE 4524 [illegible]   Operator: [illegible]   Surface El.:   Boring No.: [illegible]

Sample Number	Date Taken	Stratum From	Stratum To	Drive From	Drive To	Sample From	Sample To	Type of Sampler			Classification and Remarks
[illegible]	[illegible]	950	[illegible]	950	[illegible]	[illegible]	[illegible]	[illegible]			Sandstone, [illegible]
32		1008		[illegible]	[illegible]	[illegible]	[illegible]	Pitcher		[illegible]	Sand, [illegible]
33	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]				fine to medium grained, [illegible]
34				[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
35				[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
36				[illegible]	[illegible]	[illegible]	[illegible]				
37				[illegible]	[illegible]	[illegible]	[illegible]				
38				[illegible]	[illegible]	[illegible]	[illegible]				grain size [illegible]
39				[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
40				[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
41				[illegible]	[illegible]	[illegible]	[illegible]				
42			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
43		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]				Clay shale, dark gray to black,
44				[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
45				[illegible]	[illegible]	[illegible]	[illegible]				[illegible] slickensides
46			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
47		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	Sand, [illegible]

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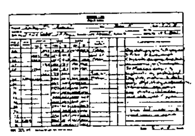

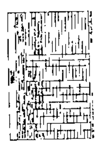

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